A Multi Expert Decision Support Tool for the Evaluation of Advanced Wastewater Treatment Trains: A Novel Approach to Improve Urban Sustainability

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Abstract

Wastewater Treatment (WWT) for water reuse applications has been accepted as a strategic solution in improving water supplies across the globe; however, there are still

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various challenges that should be overcome. Selection of practical solutions is then required whilst considering technical, environmental, socio-cultural, and financial factors. In this study, a multi expert decision support tool that considers a variety of evaluation criteria is proposed to provide a ranking system for competing advanced WWT technologies in terms of their performance. Two scenarios of water reuse in the contexts of Brazil and Greece are defined, and evaluation is undertaken based on opinions of water reuse experts. The results prove that the tool would successfully facilitate rigorous and methodical analysis in evaluation of WWT technologies for water reuse applications with potential for use under various sets of evaluation criteria, WWT technologies and contexts.

Keywords: Water reuse; technology selection; group decision making; membrane technologies; environmental impacts

1 Introduction

The global population has doubled to seven billion people in half a century, placing considerable pressure on water resources. It is projected that by 2025, 67% of the global population will face significant water stress and 35% will suffer high constraints in accessing fresh water (Lazarova et al., 2001). Additionally, it is predicted that in the coming decades crowded urban settlements, that will generate heavy loads of water pollutants, will form a large proportion of the habitable world with higher levels of water withdrawal both for domestic and industrial use (Rosegrant et al., 2011). One potential solution to reducing water stress would be the application of water reuse technologies. Water reuse both augments opportunities for natural water quality improvement and improves management of competitive water demands.

There have already been various configurations of Wastewater Treatment (WWT) trains (Joksimovic et al., 2006), including membrane-assisted technologies, that have been acknowledged as suitable and reliable solutions regarding the removal of emerging pollutants and have been capable of meeting different water reuse standards (Dogan et al., 2016). However, the complexity of the advanced unit processes, together with solution variety, requires a systematic assessment so as optimum solutions are able to be identified and selected. In fact, to find a practical solution is often rather complex, as a wide range of decision requirements and uncertain conditions should be taken into account (Dheena and Mohanraj, 2011).

Regulations have also been an important obstacle to water reuse implementation (Casani et al., 2005), as they can significantly affect the number and type of solutions and further complicate the process of decision making. This has recently received more attention from the stakeholders and a number of regional, national, and international guidelines or regulations have been established; for example, the World Health Organisation (WHO) has published a number of guidelines on water reuse (for both non-potable and potable water) and wastewater management (WHO, 2017, 2006a, 2006b). Another well-established water reuse guidelines are developed by the US Environmental Protection Agency (USEPA) (USEPA, 2012). A number of countries, such as India and China, have issued their own national water reuse standards/regulations (Eldho, 2014; Sadr et al., 2018; Yi et al., 2011; Zhu and Dou, 2018), however, in many other countries, local regulators still develop their own water reuse standards on a “case-by-case” basis (Casani et al., 2005).

Multi-Criteria Decision Analysis (MCDA) is a well-established decision support method that strives to model expert thoughts and reasoning, and illustrates modelled results by systematic procedures (Cakir and Canbolat, 2008), whilst evaluating a number of solutions based on a set of criteria (Walker et al., 2015) with respect to economic, environmental, social and technical aspects (Sadr et al., 2015). Decisions, involving various issues, in particular environmental concerns and their associated policies and regulations, oblige the participation of multiple stakeholders, as these decisions may have both local and global impacts on the environment and/or the society (Kalbar et al., 2013). To this end, the aim of any group decision activity is to identify the alternatives that are assessed by a set of individuals as the optimum ones. To achieve a more realistic approach, the experts are asked to assess not only the range of ‘agree-disagree’ but also they are requested to provide intermediate degrees as well, corresponding to partial agreement (Bordogna et al., 1997).

Taking into account the fuzziness in Group Decision Making (GDM) and the fact that the main contributors are experts, linguistic values can be employed, instead of numerical ones. These values are used both for assigning the weights of criteria and for evaluating each alternative against different criteria. Multi-Criteria Multi-Expert Decision Making (MCMEDM) has already been proved to be a useful tool to achieve rankings based on experts’ judgement (Chen, 2001, 2000). In GDM, the approaches that are adopted for the aggregation of experts’ opinions play a major role (Fan and Liu, 2010). Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) and Analytic Hierarchy Process (AHP) are commonly employed in the MCDA models and tools (especially for

GDM) (Agrawal et al., 2016; Behzadian et al., 2012; Jaiswal and Mishra, 2017; Zyoud et al., 2016). TOPSIS is the most preferred method when decision problems involve large numbers of criteria and technologies, especially if there are bits of quantitative information in the data (Kalbar et al., 2013); whereas, the AHP is a quite powerful technique when the criteria function autonomously (Behzadian et al., 2012). Hybrid models/tools of TOPSIS and AHP have also been developed and applied to different fields (Ertuğrul, 2011; Jolai et al., 2011; Tavana and Hatami-Marbini, 2011; Yousefi and Hadi-Vencheh, 2010). To date and to the best of the authors' knowledge, only few pieces of research focused on fuzzy based TOPSIS-AHP group decision making (i.e. multi-expert decision making) in wastewater treatment and water reuse applications (Kamble et al., 2017; Karahalios, 2017; Zyoud et al., 2016).

This study builds on the work previously presented by Sadr et al., (2015), which adapted an MCMEDM (fuzzy-TOPSIS) for the selection of WWT options in different water reuse situations. In brief, Sadr et al., (2015) addressed a number of critical challenges in water reuse technology selection; namely: (1) alleviated the challenges of using linguistic variables, (2) incorporated opinions of different stakeholders in a panel of decision-making, (3) Showed how to deal with numerous water reuse aspects, criteria, and technologies, and finally, (4) systematised and classified the plethora of information about water reuse scenarios, criteria, and technologies.

In this work, we implemented an improved GDM method via integrating fuzzy TOPSIS with AHP for the selection of WWT technologies for non-potable water reuse applications in different contexts with distinct regulations and different geographical, environmental, economic and demographic conditions. The approach was tested and validated by application to two case studies: (1) in São Paulo, Brazil, and (2) in Herakleion, Greece.

2 Methodology

Based on the lessons learnt from the previous study, we aimed to conduct this study in six phases (see Figure 1). The first phase develops an improved version of MCMEDM (i.e. IMCMEDM) in order to evaluate membrane-assisted water reuse technologies. The second phase involves the development of water reuse scenarios in the contexts of Brazil and Greece. Part of this phase is to identify and delineate the regions as local for water reuse application. It also explores the existing regulations, guidelines and standards for wastewater treatment and water reuse in those regions and develops a database that enables the comparison and assessment of alternatives. Next two phases, the third and fourth, identify the most important water reuse criteria and develop a list of possible WWT technologies, respectively. The fifth phase involves designing and subsequently distributing surveys on WWT criteria and technologies, whilst the sixth and final phase aims at incorporating the thoughts of experts into the technology selection process (presented in the Result and Discussion Section).

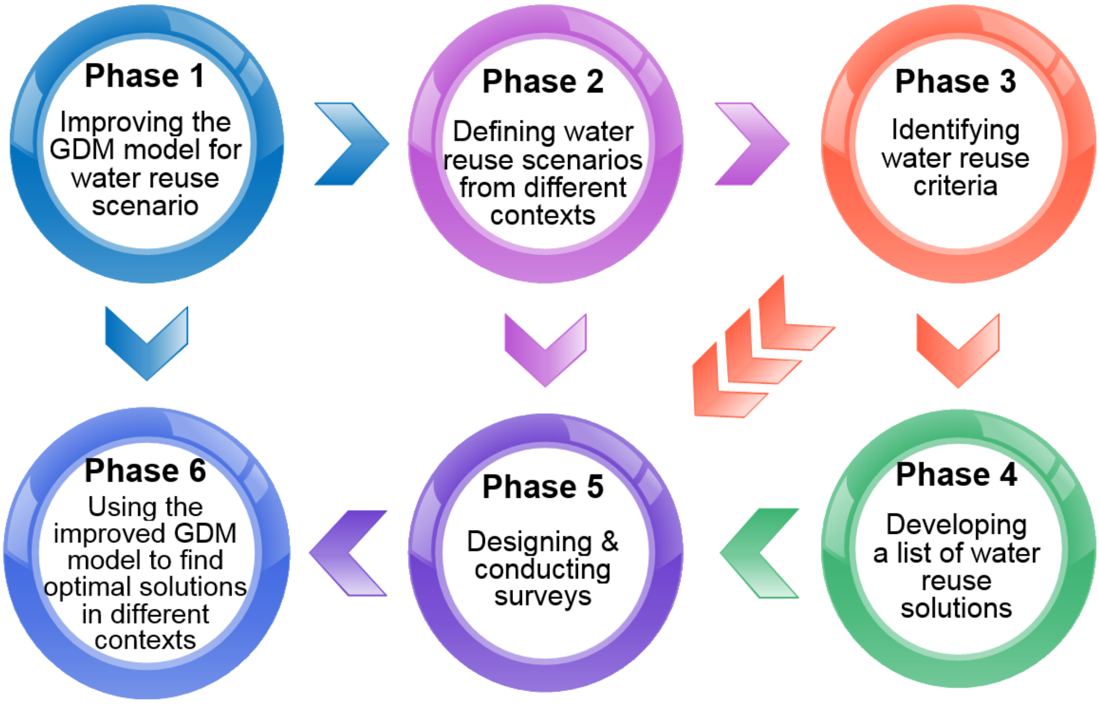


Figure 1: The six phases towards selection of wastewater treatment technologies different water reuse scenarios

2.1 Phase 1: Improved MCMEDM Method for multi expert technology selection

The improved MCMEDM (IMCMEDM) is considered as an integrated TOPSIS-AHP (i.e. Technique for Order of Preference by Similarity to Ideal Solution - Analytic Hierarchy Process) with all details of the TOPSIS model applied for evaluation of WWT technologies being found in the study of Sadr et al., 2015 . The main advantage of this new approach over the conventional MCMEDM is the pair-wise comparison of criteria. Although previous results matched existing water reuse case studies, the evaluation of criteria by the experts - who have participated in both surveys - was reported problematic due to lack of an appropriate and convenient comparison approach for the evaluation of water reuse criteria. They also indicated that pair-wise comparison of criteria would make the evaluation process less biased and more precise, and ease it, although it would be slightly more time-consuming. The pair-wise comparison was considered for this study as it will help in improving the user's (water reuse experts or stakeholders) satisfaction and in making the IMCMEDM approach more user-friendly. The pair-wise comparison of criteria results in numerical values corresponding to rows (j) and columns (k): matrix element: C_{jk}, where criterion C_j is compared against C_k:

$$\mathbf{C_{kj}} = \frac{\mathbf{1}}{\mathbf{C_{jk}}}$$

Equation 1

For diagonal elements, where $\mathbf{j} = \mathbf{k}$, we have:

$$\mathbf{C_{jk}} = \mathbf{C_{kj}} = \mathbf{1}$$

Equation 2

And:

$$\mathrm{TW_j} = \sum_{K=1}^{n} \mathrm{C_{jk}}$$

Equation 3

where: TW_j denotes total score for the j-row. To normalize the fuzzy number, the sum of scores of all rows is required:

$$\mathbf{Sum} = \sum_{j=1}^{n} \mathbf{TW_j} = (\mathbf{Sum_1}\,, \mathbf{Sum_2}\,, \mathbf{Sum_3})$$

Equation 4

where: Sum_1, Sum_2, and Sum_3 are the three elements of a triangular fuzzy number. The importance of each criterion based on each expert's evaluation can be calculated as follows:

$$\mathbf{W_{aj}^{k}} = \left(\frac{\mathbf{TW_{1J}^{k}}}{\mathbf{Sum_1}}, \frac{\mathbf{TW_{2J}^{k}}}{\mathbf{Sum_2}}, \frac{\mathbf{TW_{3J}^{k}}}{\mathbf{Sum_3}}\right), \qquad \mathbf{a} \in \{\mathbf{1}, \mathbf{2}, \mathbf{3}\}$$

Equation 5

where: *a* and *k* denote the order of elements in a triangular fuzzy number and the numbers given by each expert, respectively.
The linguistic variables and their attributed fuzzy sets that are required to rate the WWT technologies under the evaluation criteria are presented in Table 1(a).
The rating of technologies against different criteria and their weights by k decision makers are computed by Equations 6 and 7, respectively (Chen, 2001, 2000):

$$\mathbf{\tilde{x}_{ij}} = \frac{\mathbf{1}}{\mathbf{K}}\left[\mathbf{\tilde{x}_{ij}^{1}} + \mathbf{\tilde{x}_{ij}^{2}} + \cdots + \mathbf{\tilde{x}_{ij}^{K}}\right] = \left(\frac{\mathbf{1}}{\mathbf{K}}\sum_{p=1}^{K} \mathbf{x_{1ij}^{P}}, \frac{\mathbf{1}}{\mathbf{K}}\sum_{p=1}^{K} \mathbf{x_{2ij}^{P}}, \frac{\mathbf{1}}{\mathbf{K}}\sum_{p=1}^{K} \mathbf{x_{3ij}^{P}}\right) = (\mathbf{x_{1ij}}, \mathbf{x_{2ij}}, \mathbf{x_{3ij}})$$

Equation 6

$$\mathbf{W_{aj}^{k}} = \widetilde{\mathbf{w}}_{\mathbf{j}} = \frac{\mathbf{1}}{\mathbf{K}}\left[\widetilde{\mathbf{w}}_{\mathbf{j}}^{\mathbf{1}} + \widetilde{\mathbf{w}}_{\mathbf{j}}^{\mathbf{2}} + \cdots + \widetilde{\mathbf{w}}_{\mathbf{j}}^{\mathbf{K}}\right] = \left(\frac{\mathbf{1}}{\mathbf{K}}\sum_{\mathbf{p=1}}^{\mathbf{K}} \mathbf{w_{1j}^{P}}, \frac{\mathbf{1}}{\mathbf{K}}\sum_{\mathbf{p=1}}^{\mathbf{K}} \mathbf{w_{2j}^{P}}, \frac{\mathbf{1}}{\mathbf{K}}\sum_{\mathbf{p=1}}^{\mathbf{K}} \mathbf{w_{3j}^{P}}\right) = (\mathbf{w_{1j}}, \mathbf{w_{2j}}, \mathbf{w_{3j}})$$

Equation 7

where: $\tilde{x}_{ij}^{k}$ is the rating and $\tilde{w}_{aj}^{k}$ is the weight of the criterion given by the k-expert, who participated in the survey. The defined linguistic variables and the corresponding fuzzy sets for evaluation of the criteria are presented in Table 1(b).

The Fuzzy Decision Matrix (FDM) is then normalised (Equations 8 and 9) with a view to ensuring compatibility between qualitative and quantitative criteria, alleviating the normalisation challenges in the older versions of TOSIS models, and achieving the closed interval of [0,1].

$$\mathbf{R} = \left[\tilde{\mathbf{r}}_{\mathbf{ij}}\right]_{\mathbf{m\times n}} \quad \mathbf{i = 1, 2, \ldots, m} \quad \mathbf{j = 1, 2, \ldots, n}$$

Equation 8

where: R is the normalised matrix of the fuzzy decision, and $\tilde{\mathbf{r}}_{\mathbf{ij}}$ is equl to:

$$\tilde{\mathbf{r}}_{\mathbf{ij}} = \left(\frac{\mathbf{x_{1ij}}}{\mathbf{C_{1j}^{*}}}, \frac{\mathbf{x_{2ij}}}{\mathbf{C_{2j}^{*}}}, \frac{\mathbf{x_{3ij}}}{\mathbf{C_{3j}^{*}}}\right) = (\mathbf{r_{1ij}}, \mathbf{r_{2ij}}, \mathbf{r_{3ij}}) \qquad \mathbf{C_{j}^{*}} = \mathbf{max_{i}C_{ij}}$$

Equation 9

In this step, the weights are incorporated into the normalized FDM (Equation 10). Each element ($\tilde{v}_{ij}$) is calculated by using Equation 11 (Anagnostopoulos et al., 2008):

$$\widetilde{\mathbf{V}} = \left[\tilde{\mathbf{v}}_{\mathbf{ij}}\right]_{\mathbf{m\times n}} \quad \mathbf{i = 1, 2, \ldots, m} \quad \mathbf{j = 1, 2, \ldots, n}$$

Equation 10

$$\tilde{\mathbf{v}}_{\mathbf{ij}} = \tilde{\mathbf{r}}_{\mathbf{ij}} \otimes \widetilde{\mathbf{w}}_{\mathbf{j}} = (\mathbf{r_{1ij}}, \mathbf{r_{2ij}}, \mathbf{r_{3ij}}) \otimes (\mathbf{w_{1ij}}, \mathbf{w_{2ij}}, \mathbf{w_{3ij}}) = (\mathbf{r_{1ij}w_{1ij}}, \mathbf{r_{2ij}w_{2ij}}, \mathbf{r_{3ij}w_{3ij}}),$$
$$\mathbf{r_{1ij}} \geq \mathbf{0}, \mathbf{w_{1ij}} \geq \mathbf{0}$$

Equation 11

where: $\otimes$ represents multiplication in a fuzzy environment. It is noteworthy that the weights given (by the experts) to the evaluation criteria very much depend on and are affected by the context and its environmental, social and technical conditions. The weights may also be influenced by water reuse regulations and guidelines implemented in the region of interest.

Once the fuzzy positive-ideal solution ($\mathbf{A^{+}} = (\mathbf{D_{1}^{+}}, \mathbf{D_{2}^{+}}, \ldots, \mathbf{D_{n}^{+}},)$) and fuzzy negative-ideal solution ($\mathbf{A^{-}} = (\mathbf{D_{1}^{-}}, \mathbf{D_{2}^{-}}, \ldots, \mathbf{D_{n}^{-}},)$) are defined, the vertex method is used to calculate the distance $\mathbf{D}(.,.)$ of each alternative from A^{+} and A^{-}:

$$\mathbf{D_{i}^{+}} = \sum_{\mathbf{j=1}}^{\mathbf{n}} \mathbf{D}\left(\check{\mathbf{v}}_{\mathbf{ij}}, \check{\mathbf{v}}_{\mathbf{j}}^{+}\right) = \sqrt{\frac{\mathbf{1}}{\mathbf{3}}\left[\left(\check{\mathbf{v}}_{\mathbf{1ij}} - \check{\mathbf{v}}_{\mathbf{1j}}^{+}\right)^{\mathbf{2}} + \left(\check{\mathbf{v}}_{\mathbf{2ij}} - \check{\mathbf{v}}_{\mathbf{2j}}^{+}\right)^{\mathbf{2}} + \left(\check{\mathbf{v}}_{\mathbf{3ij}} - \check{\mathbf{v}}_{\mathbf{3j}}^{+}\right)^{\mathbf{2}}\right]}$$

Equation 12

$$\mathbf{D_i^-} = \sum_{\mathbf{j=1}}^{\mathbf{n}} \mathbf{D}\left(\check{\mathbf{v}}_{\mathbf{ij}}, \check{\mathbf{v}}_{\mathbf{j}}^{-}\right) = \sqrt{\frac{\mathbf{1}}{\mathbf{3}}\left[\left(\check{\mathbf{v}}_{\mathbf{1ij}} - \check{\mathbf{v}}_{\mathbf{1j}}^{-}\right)^{\mathbf{2}} + \left(\check{\mathbf{v}}_{\mathbf{2ij}} - \check{\mathbf{v}}_{\mathbf{2j}}^{-}\right)^{\mathbf{2}} + \left(\check{\mathbf{v}}_{\mathbf{3ij}} - \check{\mathbf{v}}_{\mathbf{3j}}^{-}\right)^{\mathbf{2}}\right]}$$

Equation 13

where: $\check{v}_j^+ = \left(\check{v}_{1j}^+, \check{v}_{2j}^+, \check{v}_{3j}^+\right) = (1,1,1)$ and $\check{v}_j^- = \left(\check{v}_{1j}^-, \check{v}_{2j}^-, \check{v}_{3j}^-\right) = (0,0,0)$ when $j = 1,2, \dots, n.$

Finally, the overall performance of all WWT trains (representing their scores and ranks) is calculated by the closeness coefficient (CC_i) using Equation 14 (Chen, 2000):

$$\mathbf{CC_i} = \frac{\mathbf{D_i^-}}{\mathbf{D_i^+} + \mathbf{D_i^-}} \quad \mathbf{i = 1, 2, \dots, m}$$

Equation 14

with CC_i ranging from 0 to 1. High value of CC_i indicates better performance of the ith technology, whereas a smaller value points out that the ith solution does not perform well.

In this study, the mathematical model has been incorporated into the IMCMEDM tool. The IMCMEDM is a stand-alone decision support tool with a user-friendly Graphical User Interface (GUI) developed in a MATLAB environment. More information on the GUI is provided in the Supplemental Online Material (SOM).

Table 1: Linguistic Variables (LVs) and Fuzzy Sets (FSs): (a) employed for WWTTs rating under each criterion, (b) employed for assigning the weights of the criteria (adapted from Sadr et al., (2015)).

LVs and FSs (a) employed for WWTTs rating under each criterion			
	Linguistic variables	Code	Fuzzy sets
1	Very poor	VP	(0.00, 0.00, 0.10)
2	Poor	P	(0.00, 0.10, 0.30)
3	Medium poor	MP	(0.10, 0.30, 0.50)
4	Medium	M	(0.30, 0.50, 0.70)
5	Medium good	MG	(0.50, 0.70, 0.90)
6	Good	G	(0.70, 0.90, 1.00)
7	Very good	VG	(0.90, 1.00, 1.00)
LVs and FSs (b) employed for assigning the weights of the criteria.			
	Linguistic variables	Code	Fuzzy sets
1	Extremely less Important	ELI	(0.00, 0.00, 0.11)
2	Strongly less important	SLI	(0.00, 0.11, 0.22)
3	Moderately less important	MLI	(0.11, 0.22, 0.33)
4	Weakly (Slightly) less important	WLI	(0.22, 0.33, 0.44)
5	Equally important	EI	(0.33, 0.44, 0.55)
6	Weakly (Slightly) more important	WMI	(0.44, 0.55, 0.66)
7	Moderately more important	MMI	(0.55, 0.66, 0.77)
8	Strongly more important	SMI	(0.66, 0.77, 0.88)

9	Extremely more important	EMI	(0.77, 0.88, 1.00)

2.2 Phase 2: Defining water reuse scenarios

Prior to defining water reuse scenarios, we considered two real case studies of water reuse from different regions with different environmental, social, demographic, legislative and technological conditions. The final ranking of the treatment trains can significantly vary depending on these conditions. Here first, the geographical and environmental situations in each scenario (region) are discussed. We then investigated the water reuse legislation in both cases to ensure that the defined scenarios do not come into conflict with local regulations (especially environmental).

2.2.1 Case study 1: Sao Paulo, Brazil

Sao Paulo Metropolitan Region (SPMR) is located in the east of Brazil (Figure S1 in the SOM). The predominant climate is tropical-wet and it consists of 39 municipalities aggregating approximately 20 million inhabitants, which is 48% of the state population, (SEADE, 2012). Water reuse is becoming increasingly critical in Latin America, especially in large, populous cities with water management having become a significant challenge, mainly due to high rate of urbanisation that is not evenly distributed (Morihama et al., 2011). In SPMR, water resources are traditionally provided by surface water sources (91%), while groundwater sources are fundamental as a complement to the region's water supply (Coroado, 2012). In the early stages of regional development, increased focus on quantity rather than quality resulted in deterioration in water quality. As the implementation of water recycling and reuse schemes are currently of importance, suitable and reliable WWT technologies should be implemented to ensure promotion and protection of public health and the environment.

2.2.1.1 Water reuse legislation and guidelines in Sao Paulo, Brazil

Although no specific water reuse guidelines have been officially developed in Brazil, there are few general policies related to water reuse; the most relevant one was passed on November 2005 by the National Council of Water Resources, Resolution nº 54. This regulation focuses only on the definitions of permitted water reuse categories and general procedures for management of water reuse schemes; although no quality standards were proposed.

There is a guideline from the Brazilian Association of Technical Standards, NBR 13, 969, which does focus on water re-use applications in a few sections (ABNT, 1997). In particular, Section 6 specifies general orientation for implementing local water reuse schemes and also proposes four classes of non-potable water reuse, according to its intended application. Comparing the local water quality standard in NBR 13,969 with quality standards in other international guidelines (USEPA, 2012; WHO, 2017, 2006a), this standard can hardly be accepted for any reuse application in urban areas. Due to the growing rate of water consumption and increasing interest in water recycling and reuse, a water reuse scheme was developed by Sabesp in 2002. It enforced SPMR to use treated effluent for public place washing, parks, gardens, and sportive field irrigation, and was regulated by Decree n° 44,128 (Sao Paulo, 2012), which states that the water companies especially water suppliers should be consulted with regard to the standards of the physical, chemical and microbiological properties of reused water (Coroado, 2012). In 2005, the Sao Paulo City Hall mandated a more comprehensive law in the "Municipal Program for Water Conservation and Rational Use in Households and Buildings".

In addition, many industries started to plan the implementation of water reuse schemes by developing their own guidelines proposing specific quality standards. This approach resulted in individual agreements among the reuse water users and suppliers. The most remarkable agreement was the one between the AQUAPOLO Project and the CAPUAVA Industrial Complex, which resulted in a reuse water quality standard that would only be complied if advanced wastewater treatment technologies were applied. In this case the restrictions imposed for the industries, because of fresh water scarcity challenges in the SPMR and by the industries for the water suppliers, driven the decision-making process for the definition of the final wastewater treatment arrangement using advanced technologies.

2.2.1.2 Defining a scenario of water reuse application in Sao Paulo, Brazil

In SPMR, there are a number of water reuse projects and programmes - (e.g., Sabesp, AQUAPOLO). In this study, we focused on the AQUAPOLO Project, which appears to be a suitable one for testing and validating the IMCMEDM approach. AQUAPOLO is one of the largest WWT plants in Latin America where 1 $m^3 s^{-1}$ of effluent is treated by Membrane Bioreactor (MBR) and Reverse Osmosis (RO) units. It is then distributed to the CAPUAVA petrochemical complex in Maua city (Ambiental, 2011). More information on this case study is provided in the SOM (Table S1). This project aimed to establish sustainable practices of water reuse (Coroado, 2012), and based on the fact that water reuse practices have become critical for Sao Paulo, the following scenario was considered: Scenario 1: WWT through advanced technologies (membrane-assisted) for industrial water reuse, e.g., cooling towers.

2.2.2 Case study 2: Herakleion, Greece

The study focuses on Herakleion, which is the fourth largest city in Greece and is located at the north of Crete. Crete is about 8,336 km^2 with approximately 600,000 residents (Figure S2 in the SOM). Greece is considered as a water-stressed country (EEA, 2005). In the early 1990s, total water consumption was reported about 5,500 million m^3 y^{-1}, while this amount increased to 7,150 million m^3y^{-1} in 2000, indicating an increase of 3% each year (EEA, 2005). Furthermore, fresh water resources are unevenly distributed with some regions suffering from water scarcity particularly in summer due to low precipitation and high demand (Tsagarakis et al., 2004). To tackle the problem, the country is compelled to use alternative water resources alongside an appropriate water management methods. To this end, an established framework for community action in the field of water policy was introduced via the implantation of the European Union Water Framework Directive (WFD) stating that for communities of more than 2,000 population equivalent, collection and treatment (up to secondary treatment) of wastewater is required.

2.2.2.1 Water reuse legislation and guidelines *in Greece*

In 2011, the Greek parliament adopted legislation (354B/2011) to exploit treated wastewater as a renewable resource. Specifically, the legislation refers to the following water reuse purposes (Greek Gazette, 2011): 1) WWT for irrigation including both restricted and unrestricted irrigation, 2) recharge of underground aquifers and reduction in seawater intrusion, 3) urban reuse, and 4) wastewater reuse for industrial activities. According to Bixio et al., (2006), 23 million m^3 d^{-1} of wastewater is reused in Greece, representing around 10% of total WWT plant (WWTP) effluent. Freshwater, currently used for agricultural purposes, can be retained for high-priority applications (Aggelides et al., 2005).

2.2.2.1 Defining a scenario of water reuse application in Herakleion, Greece

The operation of Herakleion Wastewater Treatment Plant (WWTP) started in 1996 and it is going to operate until its environmental terms expire in June 2020. The WWTP, currently serving the municipalities of Herakleion and Gazi, meets the demands of about 200,000 inhabitants. Domestic wastewater is primarily conveyed to the plant through the sewerage system, whilst tanker trucks serve a small portion of the population (7,000 people). It is worth noting that the Herakleion plant is a municipal WWTP and does not treat industrial wastewater (YPEKA, 2012).

The current WWTP includes the following units (EDEYA, 2015): screens (pore size: 9 mm), two units of aerated grit chambers, two Primary Sedimentation Tanks (PST), a selection tank, five chambers and six agitators, two lines of two aerobic-anoxic tanks per line, two Secondary Sedimentation Tanks (SST), and disinfection with NaOCl (15%) in channels at the perimeter of SST, with treated effluent being discharged at sea (Kazos, 2013). Recently, an expansion of the WWTP has been proposed to help meet the demands of an additional 30,000 people. The expansion will be based on membrane technologies, in particular, MBRs are planned to be implemented (Kazos, 2013). The redeveloped WWTP is going to treat 36,000 m^3 d^{-1}, corresponding to 194,000 people (EDEYA, 2015). The expected characteristics of effluent after the adaptation are provided in the SOM (Table S2). The following scenario is then defined for reuse of the WWTP effluent in Herakleion: Scenario 2: WWT using membrane technology for unrestricted agricultural irrigation in Herakleion.

2.3 Phase 3: Justification of the evaluation criteria

Depending on the water reuse scenario, the number of criteria and weights of each selected criterion are different. Sweetapple et al., (2014) evaluated five criteria (objectives) in their research, Joksimovic et al., (2006) considered eight criteria, Flores-Alsina et al., (2008) and Sadr et al., (2016) considered nine, and finally Sadr et al., (2015) employed ten criteria. However, regardless of the number of evaluation criteria, it is imperative to consider the following aspects: (1) economic, (2) technical, (3) social and (4) environmental. As this study implemented an improved version of MCMEDM model developed by Sadr et al., 2015, similar evaluation criteria will be considered (See Figure S3, in the SOM).

2.4 Phase 4: Justification of the WWT trains

Each WWT train comprises a number of unit processes, which can be categorised into the four standard stages of treatment: 1) Primary Treatment (PT) 2) Secondary Treatment (ST) 3) Tertiary Treatment (TT) and 4) Disinfection (DI). There are various unit processes to be considered in each stage, therefore, a large number of WWT trains can be formed by different unit processes. Joksimović, (2006) calculated the number of possible WWT technologies for different water reuse purposes, e.g. 190 treatment trains for irrigation re-use and 149 for indirect-potable water re-use. Considering the availability of technologies and feasibility of their installation, operation and maintenance in the targeted regions, ten WWT technologies have been shortlisted for the final evaluation by the water re-use experts in this study (Figure 2).

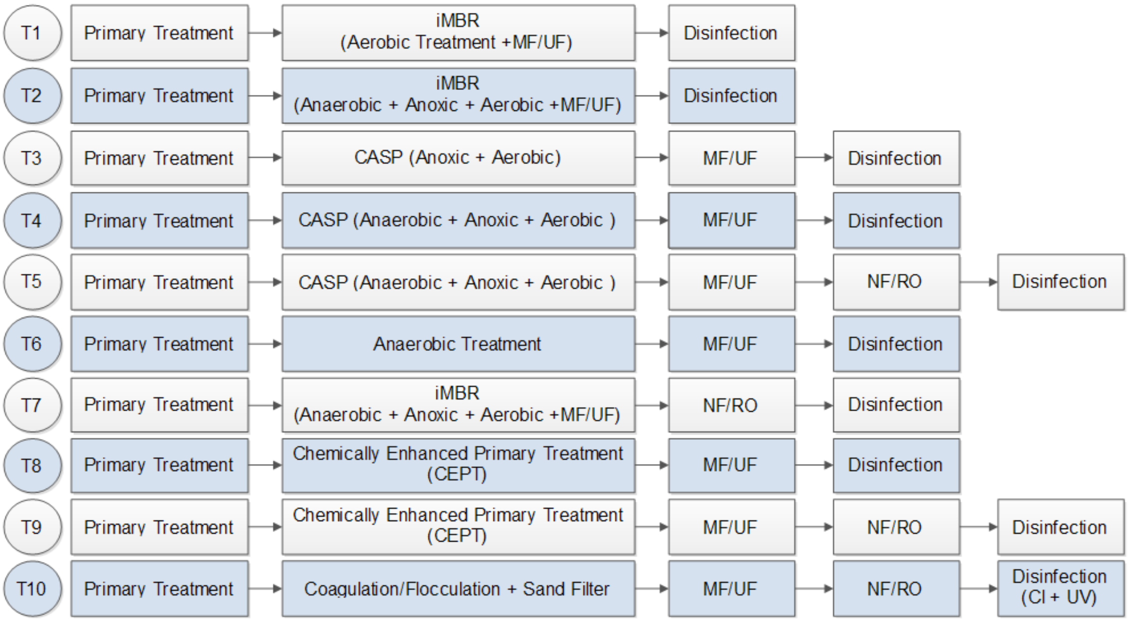


Figure 2: Membrane assisted WWT trains shortlisted and employed in this study

2.5 Phase 5: Evaluation by water re-use experts

Based on the description and characteristics of the defined scenarios and the proposed mathematical approach of the IMCMEDM, two questionnaires (as part of the IMCMEDM tool) were prepared and distributed to a number of wastewater engineers and water reuse experts (from both the academia and industry) in Brazil and Greece. The participants were selected based on the contexts (scenarios) and their areas of expertise. In this study, similar to many other TOPSIS-based GDM approaches, a number of experts were invited (three in Scenario 1 and four in Scenario 2) and all experts were regarded as equally qualified and competent (Agrawal et al., 2016; Behzadian et al., 2012; Chen, 2001; Jaiswal and Mishra, 2017; Tavana and Hatami-Marbini, 2011; Zyoud et al., 2016).

Expert responses were incorporated into the IMCMEDM tool to build decision-making matrices for different scenarios (Phase 6). Table 2 illustrates the experts' responses (in Scenario 1) for the appraisal of WWT trains against different decision criteria. The colour-coded ratings in Table 2 shows that generally the technology ratings (under each criterion) are similar for all the experts. However, there were few disparities between the given rates as well, for example, the rating of T5 against C8 (land requirement) were different, where Experts 1, 2 and 3 assigned the rates of Good (G), Medium Poor (MP) and Poor (P) to T5 respectively. On the other hand, the pair-wise comparison of the decision criteria were more diverse among the experts as expected (see Tables S3 to S9, in the SOM). This is due to the fact that each expert generally has different priorities and preferences. Again this is where a powerful GDM, such as the proposed approach, can merge the experts' opinions into one decision matrix and help the decision makers finalise a decision. General responses of the experts for comparison of technologies with respect to each criterion for Scenario 2 are also colour-coded and summarised in the SOM, Table S10.

3 Results and Discussion

3.1 Scenario 1: WWT through advanced technologies (membrane technology) for industrial water reuse, *e.g.* cooling towers in Sao Paulo, Brazil

As this scenario is defined based on a successful project that is under operation for several years, it is used here to validate the IMCMEDM model/tool. As mentioned in Section 2.1, the ranking system is formed based on CC_i using Equation 14, with the option with the highest value being the best technology (Figure 3(a)). For this scenario, T2 (PT → iMBR (anaerobic → anoxic → aerobic → MF/UF) → DI) and T7 (PT → iMBR (anoxic → aerobic → Microfiltration (MF)/Ultrafiltration (UF) → Nanofiltration (NF)/Reverse Osmosis (RO) → DI) obtained the top *CCs* (0.3879 and 0.3835, respectively) and therefore, they are identified as the preferred options. The least preferred technology is T9 with a score of 0.3313.

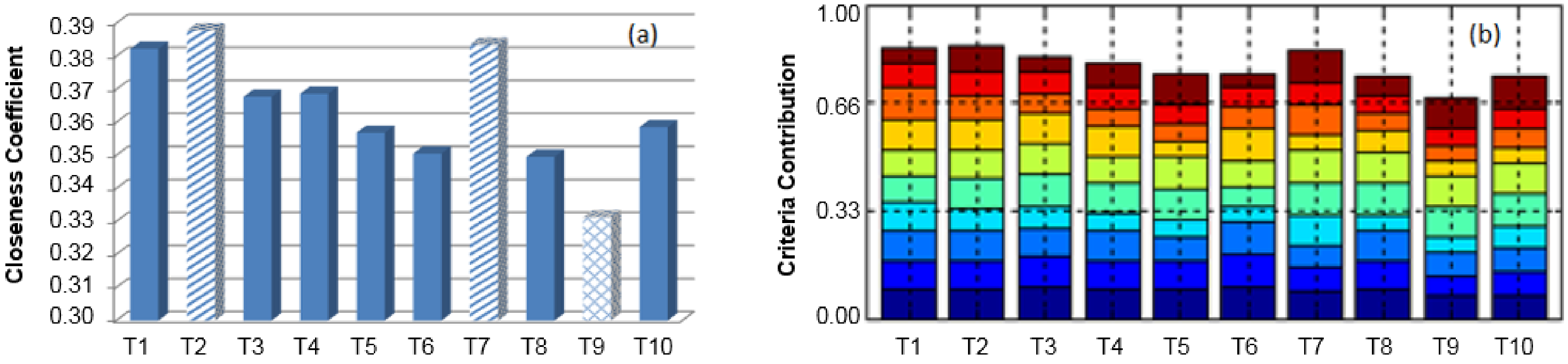
The sequence of the closeness coefficients represents the main concerns in this scenario observed by the experts in Brazil. Previous studies have reported emergent concerns over the performance of conventional treatment technologies in terms of removing emerging contaminants (Arriaga *et al.*, 2016). The WWT train at AQUAPOLO is comprised of preliminary treatment, PT, MBR, DI and RO. T7, the 2nd best technology, is basically an MBR tailed by NF or RO, followed by DI. It is interesting that RO is occasionally employed, for instance when total dissolved solids (TDS) concentration of the effluent is very high. Considering occasional implementation of RO in AQUAPOLO, T2, the 1st option selected by the IMCMEDM model, is very similar to the wastewater technology configuration in AQUAPOLO.

Table 2: The colour-coded fuzzy ratings of the treatment trains (T1 to T10) against different decision criteria (C1 to C10) by three WWT and water reuse experts (E1, E2, and E3) for Scenario 1

	C1			C2			C3			C4			C5		
	E1	E2	E3	E1	E2	E3	E1	E2	E3	E1	E2	E3	E1	E2	E3
T1	G	G	G	G	G	G	G	G	G	G	G	G	VG	MG	MG
T2	G	G	G	G	G	G	G	G	G	MG	MG	MG	G	G	G
T3	VG	VG	VG	G	G	G	G	G	G	G	M	M	VG	VG	VG
T4	G	G	G	G	G	G	G	G	G	MG	M	M	G	G	G
T5	G	G	G	G	G	G	MG	MG	MG	MG	M	M	G	G	G
T6	VG	VG	VG	VG	VG	VG	VG	VG	VG	MG	MP	MP	G	M	M
T7	MG	G	VG	MG	MG	MG	MG	MG	MG	G	G	G	VG	VG	VG
T8	G	G	G	G	G	G	G	G	G	M	M	M	VG	VG	VG
T9	MG	MG	MG	MG	M	MG	MG	MG	MG	M	M	M	VG	G	G
T10	MG	MG	MG	MG	MG	G	MG	MG	MG	MG	MG	MG	VG	VG	VG

	C6			C7			C8			C9			C10		
	E1	E2	E3	E1	E2	E3	E1	E2	E3	E1	E2	E3	E1	E2	E3
T1	VG	MG	MG	VG	G	G	VG	VG	VG	G	G	M	MG	MP	MP
T2	G	G	G	G	G	G	G	MG	MG	G	G	M	G	MG	MG
T3	VG	G	VG	G	G	G	G	MG	M	G	G	M	G	MP	MP
T4	G	MG	G	G	G	G	G	M	MP	G	G	M	G	MG	MG
T5	VG	VG	VG	M	M	M	G	MP	P	G	MG	M	VG	G	G
T6	G	M	G	VG	VG	VG	VG	MG	MG	VG	G	M	MG	MP	MP
T7	VG	VG	VG	M	M	M	G	G	G	MG	MG	M	VG	VG	VG
T8	G	G	G	MG	MG	MG	M	M	M	MG	MG	M	MG	M	M
T9	G	G	G	M	M	M	M	MP	MP	MG	MG	M	VG	G	G
T10	G	G	G	M	M	M	M	M	M	MG	MG	M	VG	VG	VG

Linguistic variables	Code
Very poor	VP
Poor	P
Medium poor	MP
Medium	M
Medium good	MG
Good	G
Very good	VG



T1	Primary treatment + iMBR (Aerobic treatment + MF/UF) + Disinfection
T2	Primary treatment + iMBR (Anaerobic + Anoxic + Aerobic + MF/UF) + Disinfection
T3	Primary treatment + CASP (Anoxic + Aerobic) + MF/UF + Disinfection
T4	Primary treatment + CASP (Anaerobic + Anoxic + Aerobic) + MF/UF + Disinfection
T5	Primary treatment + CASP (Anaerobic + Anoxic + Aerobic) + MF/UF + NF/RO + Disinfection
T6	Primary treatment + Anaerobic treatment + MF/UF + Disinfection
T7	Primary treatment + iMBR (Anoxic + Aerobic + MF/UF) + NF/RO + Disinfection
T8	Primary treatment + Chemically enhanced primary treatment (CEPT) + MF/UF + Disinfection
T9	Primary treatment + Chemically Enhanced Primary Treatment (CEPT) + MF/UF + NF/RO + Disinfection
T10	Primary treatment + Coagulation/flocculation + sand filtration + MF/UF + NF/RO + Disinfection (Chlorination +UV)

C1	Capital cost
C2	O & M Cost
C3	Energy consumption
C4	Environmental Impact
C5	Community acceptance
C6	Adaptability
C7	Ease of construction and deployment
C8	Land requirement
C9	Level of complexity
C10	Water quality

Figure 3: Results on Water Reuse Scenario 1 - AQUAPOLO: (a) the IMCMEDM bar chart (b) criteria contribution of various WWT systems

The result can also be more extensively analysed by the criteria contribution bar chart (Figure 3(b)). The dissimilarity of coloured bars illustrates that the technologies with high *CCs* generally have high performance under different evaluation criteria. This means that if an alternative obtains high rates (scores) for many or even all evaluation criteria, it is most likely to be among the alternatives with the highest performance and rankings. Figure 3(a) and 3(b) show that T1, T2 and T7 perform well whereas T5, T6, and T9 are shown to be the least preferred technologies. All the preferred alternatives have smaller footprint, which is mainly attributed to the exclusion of sedimentation tanks (ST). T7 is shown to perform well in contaminant removal (C10). In spite of its low contribution in CAPEX (C1), OPEX (C2) and energy consumption (C3), T7 is shown to be the 2nd best solution as it performs well under C4, C5, and C10.

3.2 Scenario 2: WWT using membrane technologies for unrestricted agricultural irrigation in Herakleion, Greece

In this scenario, treatment systems were evaluated against the defined criteria. Figure 4(a) illustrates that T3 and T4, which both are Conventional Activated Sludge Processes (CASP), obtain the highest *CCs* (0.3594 and 0.3441, respectively). T6 received the lowest score of 0.1843. It can be inferred that the experts believe that CASP are reliable and effective enough in terms of contaminant removal for non-potable water reuse purposes with similar WWT trains having already been suggested in previous studies and projects (Norton-Brandão *et al.*, 2013; Judd and Judd, 2011; Melin et al., 2006). Figure 4(b) shows that T3 and T4 are the preferred technologies, whilst T6 is the least preferred. T3 and T4 perform well with respect to C1, C2, and C3. T5, T7, T9 and T10 are considered as technologies with high OPEX; this is mainly associated with high energy consumption of NF/RO. These technologies are also characterised by large footprint and high investment (capital) expenditure.

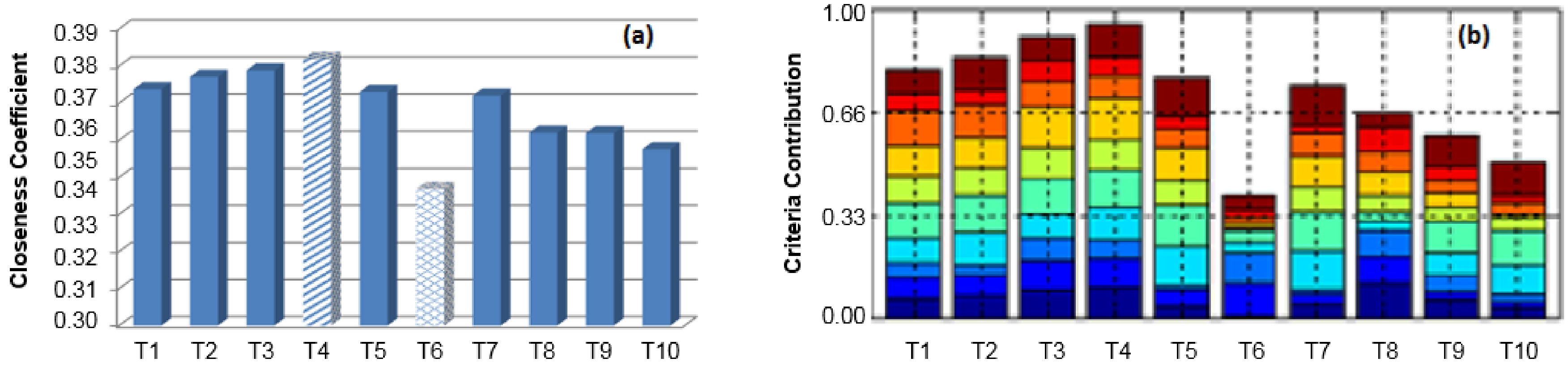
T2 consists of fewer treatment unit processes (compared to the other WWT technologies), which resulted in a smaller footprint. It is noteworthy that, although T5 does not perform well under C1 and C2, it does show high performance within the rest of the evaluation criteria and therefore, it is among the technologies with the best performance. T5, a technology leading to very high effluent quality, attained high score reflecting the water quality concerns that are associated with human health and environmental issues. Hence, T5 should be considered in locations with relatively high environmental awareness and willingness to pay. The results of this scenario pointed that participants from Greece do not consider MBR as their 1st option, in particular, when CASP are available.

3.3 Sensitivity analysis

It can be seen in the results provided in Sections 3.1 and 3.2 that generally the closeness coefficients were relatively lower in Scenario 1 compared to those in Scenario 2. This shows that the performances of the WWT trains are generally closer to that of the ideal solution (defined based on the TOPSIS approach) in Scenario 2. The closeness coefficient values of each alternative very much depend on the experts' preference and priorities, which are defined based on both the context and the experts' opinions and interests. To this end, in order to explore the sensitivity of the values of closeness coefficient (i.e. the distance of each alternative from the ideal solution with respect to different criteria) to changes in the experts' weightings, a two-at-a-time sensitivity analysis was performed in both Scenarios 1 and 2. The sensitivity analysis was focused on the weights of the evaluation criteria (namely: C1: capital cost; C2: O & M Cost; C3: energy consumption; C4: environmental Impact; C5: community acceptance; C6: adaptability; C7: ease of construction and deployment; C8: land requirement; C9: level of complexity and C10: water quality). The overall weight of each criterion were changed by ±20% in each scenario (see Figure 5).

Figure 5 and Figure S4 (in the SOM) shows that the closeness coefficients in Scenario 1 are more sensitive to changes in criteria weightings compared to those in Scenario 2. The highest sensitivity in Scenario 1 can be seen for T8 (PT + Chemically Enhanced Primary Treatment (CEPT) + MF/UF + DI), which was among the least preferred technologies in this scenario; this was observed when C5 (i.e. community acceptance) was changed (see Figures S12 and S13, in the SOM). This is due to the fact that all the experts rated this treatment train 'Medium', which is generally lower than the rates of other technologies with respect to this criteria (see Table 2). The least sensitivity in Scenario 1 was seen in the value of T2's closeness coefficient (+0.050 and -0.034), whilst the highest was observed in that of T8 (+0.248 and -0.115). In Scenario 2, T3 (+0.250 and -0.215) and T6 (+0.189 and -0.150), respectively, showed the highest sensitivity to the changes of criteria weights. In this scenario, closeness coefficients were significantly impacted by the variation in C1; where sensitivity to the (simultaneous) alteration of C1 - C6, C1 – C7 and C1 – C2 presented the highest changes among the others, whereas, in Scenario 1, alterations of C10 resulted the highest variations in the result; for example, A simultaneous increase in the weights of C10 and C6 (20% each) increased closeness coefficients by 0.072 (on average).

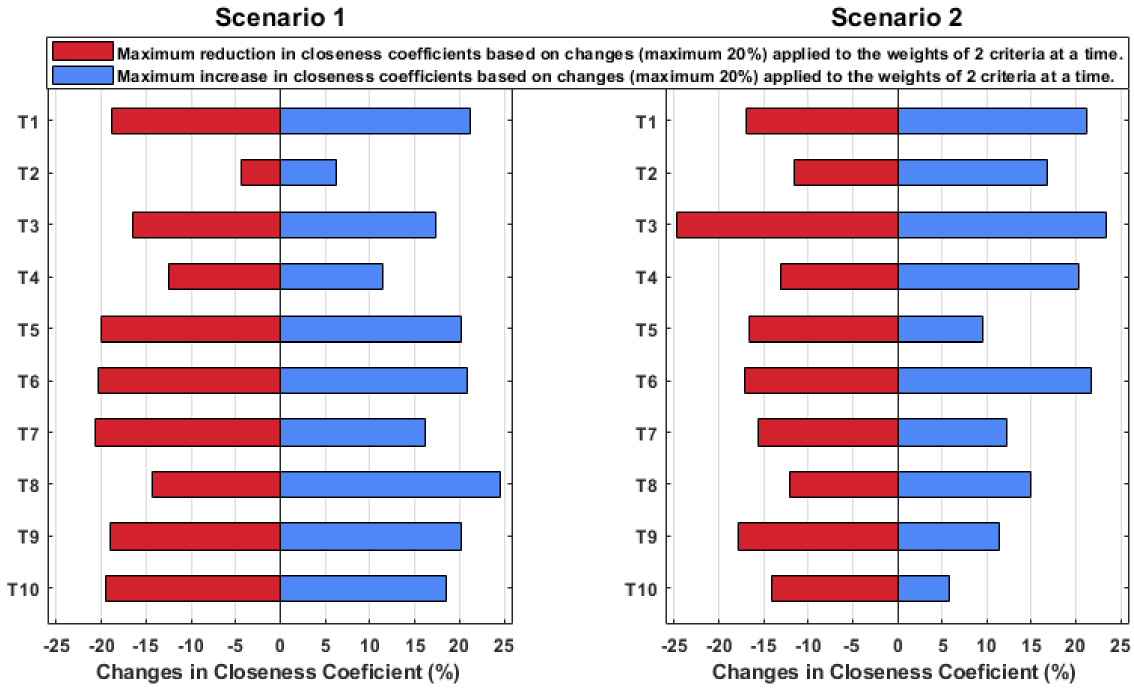
The variations and differences shown in the sensitivity analysis of Scenario 1 and Scenario 2 support the fact that the results of such GDM tools, to a certain extent, depend on the experts' opinions and preferences. Therefore, the process of selecting experts is of high importance as to determine how suitable or relevant their expertise is; this introduces a new approach in which a weight is assigned to each expert (based on their knowledge and experience or some other factors) in the group decision making process (Pang et al., 2017; Yang et al., 2017; Yue, 2012). However, this is out of the scope of the current study, but would be a good addition for future research. In this study, similar to several other GDM approaches (Agrawal et al., 2016; Behzadian et al., 2012; Kalbar et al., 2013; Ren and Liang, 2017), all experts were regarded as equally important and pertinent. The design of the survey (questionnaire) or the tool (which contains the survey) would have meaningful impacts on the results of the study (Bowling, 2005; Jonker and Kosse, 2009; Nardi, 2018).



T1	Primary treatment + iMBR (Aerobic treatment + MF/UF) + Disinfection
T2	Primary treatment + iMBR (Anaerobic + Anoxic + Aerobic + MF/UF) + Disinfection
T3	Primary treatment + CASP (Anoxic + Aerobic) + MF/UF + Disinfection
T4	Primary treatment + CASP (Anaerobic + Anoxic + Aerobic) + MF/UF + Disinfection
T5	Primary treatment + CASP (Anaerobic + Anoxic + Aerobic) + MF/UF + NF/RO + Disinfection
T6	Primary treatment + Anaerobic treatment + MF/UF + Disinfection
T7	Primary treatment + iMBR (Anoxic + Aerobic + MF/UF) + NF/RO + Disinfection
T8	Primary treatment + Chemically enhanced primary treatment (CEPT) + MF/UF + Disinfection
T9	Primary treatment + Chemically Enhanced Primary Treatment (CEPT) + MF/UF + NF/RO + Disinfection
T10	Primary treatment + Coagulation/flocculation + sand filtration + MF/UF + NF/RO + Disinfection (Chlorination +UV)

C1	Capital cost
C2	O & M Cost
C3	Energy consumption
C4	Environmental Impact
C5	Community acceptance
C6	Adaptability
C7	Ease of construction and deployment
C8	Land requirement
C9	Level of complexity
C10	Water quality

Figure 4: Results on Water Reuse Scenario 2 - Herakleion: (a) the IMCMEDM bar chart (b) criteria contribution of various WWT systems



T1	Primary treatment + iMBR (Aerobic treatment + MF/UF) + Disinfection
T2	Primary treatment + iMBR (Anaerobic + Anoxic + Aerobic + MF/UF) + Disinfection
T3	Primary treatment + CASP (Anoxic + Aerobic) + MF/UF + Disinfection
T4	Primary treatment + CASP (Anaerobic + Anoxic + Aerobic) + MF/UF + Disinfection
T5	Primary treatment + CASP (Anaerobic + Anoxic + Aerobic) + MF/UF + NF/RO + Disinfection
T6	Primary treatment + Anaerobic treatment + MF/UF + Disinfection
T7	Primary treatment + iMBR (Anoxic + Aerobic + MF/UF) + NF/RO + Disinfection
T8	Primary treatment + Chemically enhanced primary treatment (CEPT) + MF/UF + Disinfection
T9	Primary treatment + Chemically Enhanced Primary Treatment (CEPT) + MF/UF + NF/RO + Disinfection
T10	Primary treatment + Coagulation/flocculation + sand filtration + MF/UF + NF/RO + Disinfection (Chlorination +UV)

Figure 5: Sensitivity of closeness coefficients in each scenario to a two-at-a-time alteration of criteria weights (±20%) for the wastewater treatment trains evaluated in this study

4 Conclusions and Implications

Modifications and improvements were made to the MCMEDM model that has been previously presented by Sadr *et al.* in 2015. The new improved model (IMCMEDM) was incorporated into a decision support tool with a user-friendly GUI. The tool, which integrates TOPSIS with AHP, provided a ranking system for comparing WWT trains in terms of their performance. Two scenarios of water reuse and WWT in the contexts of Brazil and Greece were proposed with respect to ten criteria in order to select reliable options within a set of ten pre-shortlisted WWT trains. The decision-making process was first conducted by the development and distribution of two questionnaires to a number of participants from different areas of expertise from both academia and the industry. Then, the collected data formed the decision matrices used in the IMCMEDM tool. Hence, the tool provides a streamlined and robust framework in order to guide decision makers in the decision process. Notably, the contributions of designated experts in the field is formalised and thus standardised. This fact renders the decision process significantly less vulnerable to personal bias as long as an appropriate (or a manageable) number of experts is involved. Furthermore, the user-friendly GUI levels an important barrier for implementation by policy decision makers. A first scenario regarding water reuse in Sao Paulo, Brazil, was proposed based on an existing industrial water reuse project to validate the tool. The results of this scenario coincided with the project in Sao Paulo. Next, a second scenario that focussed on water reuse applications in Greece was investigated and it showed that CASPs are still more prevalent than MBRs in this region. This represents a clear evidence that technology preference very much depends upon the context, and/or pertains to the socio-technical background of the decision makers. It thus highlights the importance of consulting with local experts in order to cover the social and regulatory context appropriately. It also confirms the fact that selecting the panel of decision makers is an important process.

In both scenarios, the participants assigned the highest weights for capital cost, operation and maintenance cost, and energy consumption. Although we observed that criteria weighing of the above criteria were rather independent from the two presented scenarios, we expect that criteria ranking depends on the location in general (i.e. footprint is more restricting in urban context). Hence, future work will extend the scenario settings to rural areas in order to account for that. Future work will concentrate on further application of this flexible tool to different sets of evaluation criteria, WWT technologies and contexts.

In this study, technologies were relatively assessed with respect to different criteria (e.g. CAPEX, OPEX and energy consumption). Future studies can incorporate the results of more-in-depth cost assessment and life cycle assessment into this tool. Such attempts would give decision makers more confidence in the results of the tool. Having investigated the process of decision making and technology selection for water reuse schemes in different contexts with distinct regulations and different geographical, environmental, economic and demographic situations, the outcomes of this piece of research would contribute substantively to the application of WWT technologies (especially membrane assisted technologies) for different water reuse scenarios.

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Supplemental Online Material

A Multi Expert Decision Support Tool for the Evaluation of Advanced Wastewater Treatment Trains: A Novel Approach to Improve Urban Sustainability

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This document consists of 26 pages, 15 tables and 9 figures.

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S1. Information on the case studies

Figure S1: AQUAPOLO, Sao Paulo and its geographical location

Table S1: Information on AQUAPOLO Project and its water reuse application

General information	
Water reuse Purpose	Industrial application
destination of treated wastewater	Mainly cooling towers and process water.
region/city/area	Santo André and Mauá
Water user	Industries - CAPUAVA Petrochemical Complex
Capacity	1,000 $m^3.s^{-1}$ (design)
Information on the reclaimed water	
Wastewater treatment plant	ABC WWTP
Location	Santo André city
Level of treatment	Tertiary treatment
Volume of water entering the scheme	350 $L.s^{-1}$ - 650 $L.s^{-1}$
Technical characteristics	
Treatment technologies	ASP + MBR (anoxic + aerobic) + disinfection + RO (where necessary)
Infrastructure	From the secondary settling tank, treated wastewater is pumped to the MBR system passing through a battery of disc filter, from the MBR, according to effluent conductivity a specific fraction is treated in a reverse osmosis tray, reuse water is stored and finally pumped to the consumers
Monitoring system	Online (supervisory system)

Figure S2: Location map of Herakleion, Greece

Table S2: Influent characteristics and effluent requirements (NAMA, (2011))

		Summer	Winter
Influent characteristics			
Equivalent inhabitants		30,000	30,000
Average daily supply (design inflow)	m^3/d	6,000	6,000
Peak hourly supply	m^3/h	1,000	1,000
BOD_5	kg/d	2,100	2,100
SS	kg/d	1,950	1,950
TN	kg/d	300	300
TN	mg/l	50	50
VSS/SS	%	75	75
TP	kg/d	102	102
Effluent requirements			
BOD_5	mg/l	10	10
SS	mg/l	10	10
NH_4-N	mg/l	2	2
NO_3-N	mg/l	10	10
N org	mg/l	2	2
TP	mg/l	15	15
Total Coli	1/ml	< 100/100	< 100/100
Faecal coli	1/ml	< 50/100	< 50/50

S2. List of evaluation criteria considered in this study

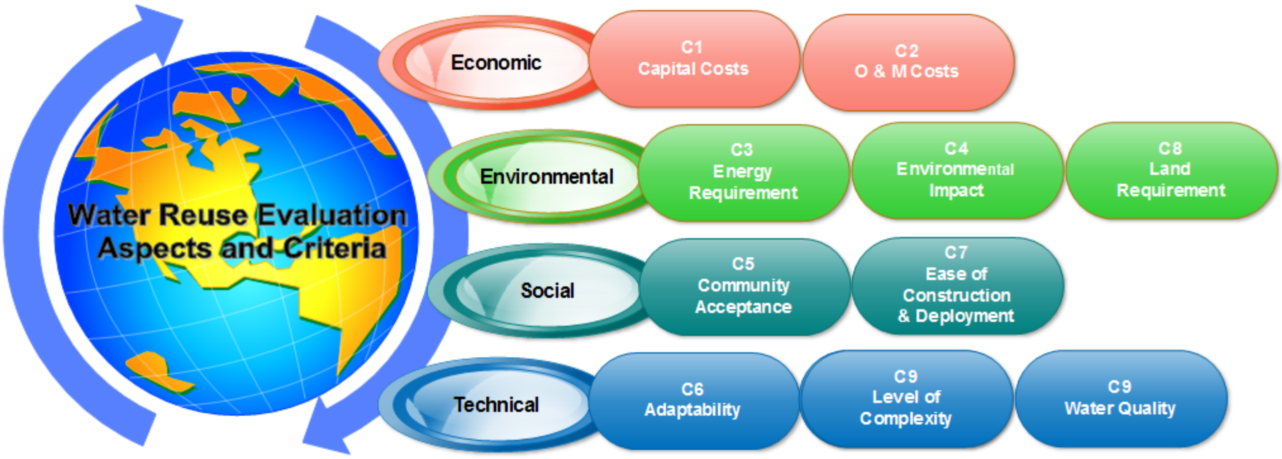

Figure S3: Water reuse criteria employed in this study

S3. Survey responses from water reuse experts – IMCMEDM tool: Water reuse scenario: Wastewater reuse through membrane assisted technologies for industrial water reuse; Case-Study of Sao Paolo, Brazil -AQUAPOLO Project

Table S3: Pair-wise comparison between the criteria (case study of Brazil – Scenario 1– Expert 1)

Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
Capital cost (C1)	EI	MLI	MLI	EI	MMI	MLI	MLI	MLI	MLI	MLI
O & M Cost (C2)	MMI	EI	EI	EI	MMI	EI	MMI	MMI	MMI	MLI
Energy consumption (C3)	MMI	EI	EI	EI	MMI	EI	MMI	MMI	MMI	MLI
Impact on environment (C4)	EI	EI	EI	EI	MMI	MMI	MMI	MMI	MMI	EI
community acceptance (C5)	MLI	MLI	MLI	MMI	EI	MLI	MLI	EI	ELI	SLI
Adaptability (C6)	MMI	EI	EI	MLI	MMI	EI	EI	MMI	EI	WLI
Ease of construction and deployment (C7)	MMI	MLI	MLI	MLI	MMI	EI	EI	WMI	EI	WLI
Land requirement (C8)	MMI	MLI	MLI	MLI	EI	MLI	MLI	EI	MMI	EI
Level of complexity (C9)	MMI	MLI	MLI	MLI	EMI	EI	EI	MLI	EI	WLI
Water quality (C10)	MMI	MMI	MMI	EI	SMI	WMI	WMI	EI	WMI	EI

Table S4: Pair-wise comparison between the criteria (case study of Brazil – Scenario 1 – Expert 2)

Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
Capital cost (C1)	EI	SLI	MLI	EI	SMI	MLI	MLI	SLI	MLI	SLI
O & M Cost (C2)	SMI	EI	EI	WMI	MMI	EI	MMI	MMI	MMI	MLI
Energy consumption (C3)	MMI	EI	EI	EI	MMI	EI	SMI	MMI	MMI	MLI
Impact on environment (C4)	EI	WLI	EI	EI	MMI	MMI	MMI	MMI	MMI	EI
community acceptance (C5)	SLI	MLI	MLI	MLI	EI	MLI	MLI	EI	ELI	SLI
Adaptability (C6)	MMI	EI	EI	MLI	MMI	EI	EI	MMI	EI	WLI
Ease of construction and deployment (C7)	MMI	MLI	SLI	MLI	MMI	EI	EI	WMI	EI	WLI
Land requirement (C8)	SMI	MLI	MLI	MLI	EI	MLI	WLI	EI	SMI	EI
Level of complexity (C9)	MMI	MLI	MLI	MLI	EMI	EI	EI	WLI	EI	WLI
Water quality (C10)	SMI	MMI	EI	EI	SMI	WMI	WMI	EI	WMI	EI

Table S5: Pair-wise comparison between the criteria (case study of Brazil – Scenario 1 – Expert 3)

Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
Capital cost (C1)	EI	WLI	MLI	EI	WMI	MLI	MLI	WLI	MLI	WLI
O & M Cost (C2)	WMI	EI	EI	WLI	MMI	EI	MMI	MMI	MMI	MLI
Energy consumption (C3)	MMI	EI	EI	EI	MMI	EI	WMI	MMI	MMI	MLI
Impact on environment (C4)	EI	WMI	EI	EI	MMI	MMI	MMI	MMI	MMI	EI
community acceptance (C5)	WLI	MLI	MLI	MLI	EI	MLI	MLI	EI	ELI	SLI
Adaptability (C6)	MMI	EI	EI	MLI	MMI	EI	EI	MMI	EI	WLI
Ease of construction and deployment (C7)	MMI	MLI	WLI	MLI	MMI	EI	EI	WMI	EI	WLI
Land requirement (C8)	WMI	MLI	MLI	MLI	EI	MLI	WLI	EI	WMI	EI
Level of complexity (C9)	MMI	MLI	MLI	MLI	EMI	EI	EI	WLI	EI	WLI
Water quality (C10)	WMI	MMI	MMI	EI	SMI	WMI	WMI	EI	WMI	EI

S4. Survey responses from water reuse experts – IMCMEDM tool: Wastewater reuse through membrane assisted technologies for unrestricted agricultural irrigation in Herakleion of Crete, Greece

Table S6: Pair-wise comparison between the criteria (case study of Greece – Scenario 2 – Expert 1)

Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
Capital cost (C1)	EI	WLI	WLI	MLI	SLI	WMI	EI	WLI	EI	SLI
O & M Cost (C2)	WMI	EI	EI	MLI	SLI	WMI	WMI	WLI	WMI	SLI
Energy consumption (C3)	WMI	EI	EI	MLI	SLI	WMI	WMI	WLI	WMI	MLI
Impact on environment (C4)	WMI	MMI	MMI	EI	EI	WMI	MMI	WMI	MMI	EI
community acceptance (C5)	WLI	SMI	SMI	EI	EI	MMI	SMI	WMI	MMI	EI
Adaptability (C6)	EI	WLI	WLI	WLI	MLI	EI	WLI	WLI	WLI	WLI
Ease of construction and deployment (C7)	WMI	WLI	WLI	MLI	SLI	WMI	EI	WLI	WLI	SLI
Land requirement (C8)	EI	WMI	WMI	WLI	WLI	WMI	WMI	EI	MMI	MLI
Level of complexity (C9)	SMI	WLI	WLI	MLI	MLI	WMI	WMI	MLI	EI	SLI
Water quality (C10)	SMI	SMI	MMI	EI	EI	WMI	SMI	MMI	SMI	EI

Table S7: Pair-wise comparison between the criteria (case study of Greece – Scenario 2 – Expert 2)

Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
Capital cost (C1)	EI	WMI	WMI	SLI	MLI	MMI	EI	MLI	EI	SLI
O & M Cost (C2)	MLI	EI	EI	SLI	MLI	MMI	EI	MLI	EI	SLI
Energy consumption (C3)	MLI	EI	EI	MLI	MLI	MMI	EI	MLI	EI	SLI
Impact on environment (C4)	SMI	SMI	MMI	EI	EI	MMI	MMI	WMI	MMI	EI
community acceptance (C5)	MMI	MMI	MMI	EI	EI	SMI	SMI	WMI	MMI	WLI
Adaptability (C6)	MLI	MLI	MLI	MLI	SLI	EI	MLI	MLI	WLI	SLI
Ease of construction and deployment (C7)	EI	EI	EI	MLI	SLI	MMI	EI	WLI	EI	MLI
Land requirement (C8)	MMI	MMI	MMI	WLI	WLI	MMI	WMI	EI	MMI	WLI
Level of complexity (C9)	EI	EI	EI	MLI	MLI	WMI	EI	MLI	EI	SLI
Water quality (C10)	SMI	SMI	SMI	EI	WMI	SMI	MMI	WMI	SMI	EI

Table S8: Pair-wise comparison between the criteria (case study of Greece – Scenario 2 – Expert 3)

Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
Capital cost (C1)	EI	WLI	WLI	MLI	MLI	WMI	EI	WMI	WMI	MLI
O & M Cost (C2)	WMI	EI	EI	MLI	MLI	WMI	WMI	WMI	WMI	MLI
Energy consumption (C3)	WMI	EI	EI	WLI	MLI	WMI	WMI	WMI	WMI	MLI
Impact on environment (C4)	MMI	MMI	WMI	EI	WLI	WMI	WMI	WMI	MMI	EI
community acceptance (C5)	MMI	MMI	MMI	WMI	EI	WMI	MMI	MMI	MMI	WLI
Adaptability (C6)	WLI	WLI	WLI	MMI	WLI	EI	WMI	WMI	WMI	MLI
Ease of construction and deployment (C7)	EI	WLI	WLI	WLI	MLI	WLI	EI	WLI	WLI	SLI
Land requirement (C8)	WLI	WLI	WLI	WLI	MLI	WLI	WMI	EI	WMI	MLI
Level of complexity (C9)	WLI	WLI	WLI	MLI	MLI	WLI	WMI	WLI	EI	SLI
Water quality (C10)	MMI	MMI	MMI	EI	MLI	MMI	SMI	MMI	SMI	EI

Table S9: Pair-wise comparison between the criteria (case study of Greece – Scenario 1 – Expert 4)

Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
Capital cost (C1)	EI	WLI	WLI	MLI	WLI	WMI	EI	WMI	WMI	SLI
O & M Cost (C2)	WMI	EI	EI	WLI	WLI	WMI	MMI	WMI	WMI	SLI
Energy consumption (C3)	WMI	EI	EI	EI	WLI	WMI	MMI	WMI	WMI	MLI
Impact on environment (C4)	MMI	WMI	EI	EI	EI	WMI	MMI	MMI	MMI	EI
community acceptance (C5)	WMI	WMI	WMI	EI	EI	WMI	MMI	WMI	MMI	WLI
Adaptability (C6)	WLI	WLI	WLI	WLI	WLI	EI	WMI	WLI	WMI	MLI
Ease of construction and deployment (C7)	EI	MLI	MLI	MLI	MLI	WLI	EI	WLI	WLI	SLI
Land requirement (C8)	WLI	WLI	WLI	MLI	WLI	WMI	WMI	EI	WMI	SLI
Level of complexity (C9)	WLI	WLI	WLI	MLI	MLI	WLI	WMI	WLI	EI	SLI
Water quality (C10)	SMI	SMI	MMI	EI	WMI	WMI	SMI	SMI	SMI	EI

Table S10: The fuzzy ratings of the technologies (T1 to T10) under all criteria (C1 to C10) by four experts (E1, E2, E3 and E4) for Scenario 2

	C1				C2				C3				C4				C5			
	E1	E2	E3	E4	E1	E2	E3	E4	E1	E2	E3	E4	E1	E2	E3	E4	E1	E2	E3	E4
T1	M	M	MP	MG	M	P	M	M	MG	P	M	M	MG	M	M	VG	P	P	P	P
T2	MP	P	P	M	M	P	MP	MP	MG	P	MP	MP	G	M	M	VG	MP	MP	MP	MP
T3	MP	M	MP	MG	MP	M	M	MG	M	G	M	MG	MG	M	M	MG	VP	VP	P	VP
T4	P	M	P	MP	P	P	MP	MP	MP	P	MP	MP	MG	M	M	MG	P	P	MP	MP
T5	VP	M	VP	VP	VP	P	P	MP	P	P	P	P	MG	M	M	MG	MG	MG	G	G
T6	P	VG	MP	MG	MP	M	M	MG	MP	M	M	G	MG	M	M	G	VP	VP	P	VP
T7	P	VG	VP	P	VP	M	P	P	P	M	P	VP	G	M	M	VG	VG	VG	G	VG
T8	M	M	MP	MG	MP	P	M	MG	MP	M	M	M	M	M	MP	M	MP	G	P	P
T9	P	P	VP	P	P	P	P	P	VP	P	P	P	M	M	MP	M	MG	G	G	MG
T10	MP	P	VP	VP	VP	M	VP	P	VP	P	VP	VP	MG	M	MP	MG	G	VG	VG	G

	C6				C7				C8				C9				C10			
	E1	E2	E3	E4	E1	E2	E3	E4	E1	E2	E3	E4	E1	E2	E3	E4	E1	E2	E3	E4
T1	MG	M	MG	MG	M	M	MG	M	M	VG	M	G	MP	M	M	MG	MP	VP	VP	VP
T2	MG	M	P	MG	MG	M	P	MG	M	VG	MP	MG	P	M	MP	M	M	MP	MP	MP
T3	MP	M	MG	MP	G	M	M	G	M	VG	VG	MG	P	M	MG	G	P	VP	VP	VP
T4	MP	M	P	MP	G	M	P	MG	M	VG	MP	P	P	P	MP	M	MP	MP	P	P
T5	MP	M	VP	MP	G	M	P	M	M	VG	P	VP	VP	VP	P	MP	MG	VG	G	G
T6	MP	VG	MG	MG	G	G	M	G	M	VG	VG	MG	P	G	MG	MG	MP	VP	VP	VP
T7	G	MG	M	G	M	G	MP	M	MP	VG	M	M	MG	MP	MP	M	VG	VG	G	VG
T8	G	M	G	MG	M	VG	G	M	MP	VG	G	MG	G	MP	G	MG	M	MP	P	P
T9	G	M	MP	MG	M	VG	P	M	P	VG	MP	M	MG	VP	MP	M	VG	G	G	G
T10	G	VG	VP	MG	M	VG	VP	MP	P	VG	VP	M	MG	VP	VP	MP	VG	G	VG	VG

Linguistic variables	Code
Very poor	VP
Poor	P
Medium poor	MP
Medium	M
Medium good	MG
Good	G
Very good	VG

S6. The final criteria weights used for each scenario

Table S11: The weights used for each scenario after incorporating the experts' ratings (estimation in real numbers)

Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	SUM
Weights in Scenario 1	0.070	0.119	0.119	0.124	0.056	0.110	0.094	0.086	0.094	0.128	1.000
Weights in Scenario 2	0.084	0.091	0.094	0.128	0.130	0.078	0.075	0.098	0.078	0.143	1.000

S7. The Details on the sensitivity analysis

Table S12: The details on the sensitivity analysis conducted in this study focusing on changes in closeness coefficients in Scenario 1 to a two-at-a-time alteration of criteria weights (by +20%); each raw presents the highest increase of closeness coefficient

	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
C1 & C2	0.0053	0.0031	0.0900	0.0235	0.0238	0.0940	0.0145	0.0809	0.0144	0.0101
C1 & C3	0.0135	0.0023	0.0846	0.0120	0.0128	0.0877	0.0152	0.0632	0.0112	0.0156
C1 & C4	0.0502	0.0029	0.0737	0.0122	0.0082	0.0219	0.0347	0.0173	0.0123	0.0002
C1 & C5	0.0002	0.0037	0.1319	0.0253	0.0256	0.0093	0.0400	0.1689	0.0323	0.0498
C1 & C6	0.0045	0.0035	0.1056	0.0056	0.0514	0.0352	0.0206	0.0487	0.0178	0.0072
C1 & C7	0.0465	0.0290	0.1040	0.0573	0.0158	0.1091	0.0192	0.0310	0.0134	0.0187
C1 & C8	0.0941	0.0004	0.0569	0.0087	0.0115	0.0747	0.0474	0.0076	0.0125	0.0119
C1 & C9	0.0035	0.0031	0.1026	0.0162	0.0064	0.0730	0.0021	0.0345	0.0035	0.0047
C1 & C10	0.0677	0.0078	0.0615	0.0150	0.0832	0.0477	0.0569	0.0286	0.0957	0.0743
C2 & C3	0.0323	0.0017	0.0390	0.0420	0.0054	0.1498	0.0180	0.1280	0.0133	0.0107
C2 & C4	0.0936	0.0126	0.0242	0.0057	0.0056	0.0332	0.0365	0.0492	0.0147	0.0063
C2 & C5	0.0000	0.0126	0.1392	0.0552	0.0572	0.0296	0.0394	0.1980	0.0471	0.0893
C2 & C6	0.0013	0.0008	0.0755	0.0078	0.1004	0.0654	0.0111	0.1127	0.0285	0.0298
C2 & C7	0.0790	0.0461	0.0834	0.0890	0.0006	0.1680	0.0116	0.0724	0.0094	0.0060
C2 & C8	0.1381	0.0056	0.0180	0.0000	0.0000	0.1134	0.0508	0.0054	0.0052	0.0015
C2 & C9	0.0202	0.0157	0.0640	0.0544	0.0392	0.1352	0.0106	0.0984	0.0090	0.0050
C2 & C10	0.0320	0.0036	0.0261	0.0369	0.1349	0.0203	0.0689	0.0242	0.1395	0.1247
C3 & C4	0.1013	0.0056	0.0012	0.0060	0.0140	0.0146	0.0366	0.0064	0.0120	0.0077
C3 & C5	0.0085	0.0060	0.1380	0.0408	0.0161	0.0110	0.0394	0.2489	0.0558	0.0790
C3 & C6	0.0010	0.0022	0.0708	0.0015	0.0615	0.0474	0.0110	0.0732	0.0380	0.0173
C3 & C7	0.0850	0.0436	0.0807	0.0863	0.0100	0.1626	0.0116	0.0400	0.0069	0.0095
C3 & C8	0.1443	0.0015	0.0029	0.0000	0.0054	0.1035	0.0512	0.0000	0.0029	0.0063

C3 & C9	0.0441	0.0075	0.0540	0.0286	0.0098	0.1226	0.0114	0.0531	0.0068	0.0094
C3 & C10	0.0291	0.0049	0.0244	0.0217	0.1082	0.0193	0.0698	0.0111	0.1506	0.1176
C4 & C5	0.0723	0.0132	0.1332	0.0228	0.0252	0.0086	0.1182	0.1848	0.0597	0.1154
C4 & C6	0.0677	0.0006	0.0642	0.0095	0.0785	0.0135	0.1090	0.0094	0.0416	0.0594
C4 & C7	0.1327	0.0478	0.0770	0.0717	0.0033	0.0982	0.0000	0.0102	0.0056	0.0000
C4 & C8	0.1707	0.0060	0.0014	0.0036	0.0000	0.0360	0.1106	0.0058	0.0015	0.0000
C4 & C9	0.1230	0.0167	0.0452	0.0091	0.0058	0.0134	0.0596	0.0102	0.0072	0.0080
C4 & C10	0.0240	0.0028	0.0242	0.0079	0.1213	0.0321	0.1302	0.0215	0.1544	0.1481
C5 & C6	0.0060	0.0042	0.0906	0.0091	0.0416	0.0090	0.0464	0.1517	0.0515	0.0673
C5 & C7	0.0279	0.0222	0.0919	0.0486	0.0199	0.0427	0.0248	0.1293	0.0152	0.0221
C5 & C8	0.0652	0.0041	0.0603	0.0144	0.0186	0.0151	0.0574	0.0898	0.0169	0.0157
C5 & C9	0.0001	0.0077	0.0888	0.0269	0.0181	0.0005	0.0295	0.1473	0.0347	0.0529
C5 & C10	0.0791	0.0084	0.0756	0.0240	0.0590	0.0524	0.0607	0.1118	0.0884	0.0916
C6 & C7	0.0638	0.0402	0.1081	0.0733	0.0017	0.1075	0.0028	0.0097	0.0014	0.0023
C6 & C8	0.1237	0.0027	0.0346	0.0040	0.0000	0.0447	0.0931	0.0000	0.0000	0.0000
C6 & C9	0.0038	0.0026	0.1071	0.0046	0.1026	0.0095	0.0268	0.0001	0.0560	0.0348
C6 & C10	0.0421	0.0071	0.0292	0.0099	0.1623	0.0309	0.1120	0.0144	0.1626	0.1492
C7 & C8	0.1313	0.0289	0.0481	0.0068	0.0193	0.1192	0.0216	0.0041	0.0140	0.0173
C7 & C9	0.0814	0.0502	0.0933	0.0923	0.0142	0.1359	0.0175	0.0012	0.0102	0.0142
C7 & C10	0.0500	0.0223	0.0411	0.0679	0.0673	0.0359	0.0341	0.0205	0.1068	0.0763
C8 & C9	0.1324	0.0065	0.0243	0.0098	0.0145	0.0619	0.0564	0.0109	0.0129	0.0115
C8 & C10	0.0636	0.0064	0.0487	0.0068	0.0543	0.0385	0.0976	0.0345	0.0852	0.0712
C9 & C10	0.0493	0.0056	0.0405	0.0265	0.1131	0.0333	0.0770	0.0208	0.1419	0.1172

Table S13: The details on the sensitivity analysis conducted in this study focusing on changes in closeness coefficients in Scenario 1 to a two-at-a-time alteration of criteria weights (by -20%); each raw presents the highest reduction of closeness coefficient

	T1	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**	**T9**	**T10**
C1 & C2	-0.0017	-0.0036	-0.0112	-0.0068	-0.0056	-0.0203	-0.0501	-0.0213	-0.0765	-0.0734
C1 & C3	-0.0035	-0.0126	-0.0072	-0.0021	-0.0427	-0.0158	-0.0510	-0.0115	-0.0710	-0.0858
C1 & C4	-0.0194	-0.0038	-0.0041	-0.0298	-0.0217	-0.0315	-0.0131	-0.0284	-0.0684	-0.0465
C1 & C5	-0.0152	-0.0029	-0.0057	-0.0005	-0.0005	-0.0385	0.0000	-0.0029	-0.0066	0.0000
C1 & C6	-0.0261	-0.0201	-0.0123	-0.0268	-0.0103	-0.0131	-0.0042	-0.0040	-0.0221	-0.0398
C1 & C7	-0.0077	-0.0060	-0.0152	-0.0118	-0.0784	-0.0189	-0.0873	-0.0022	-0.0897	-0.1064
C1 & C8	-0.0133	-0.0048	-0.0056	-0.0610	-0.0875	-0.0073	-0.0052	-0.0545	-0.1025	-0.1002
C1 & C9	-0.0004	-0.0051	-0.0081	-0.0015	-0.0019	-0.0048	-0.0235	-0.0025	-0.0582	-0.0715
C1 & C10	-0.0917	-0.0155	-0.0598	-0.0071	-0.0507	-0.0606	-0.0312	-0.0380	-0.0850	-0.0651
C2 & C3	-0.0028	-0.0083	-0.0046	-0.0057	-0.0694	-0.0188	-0.1410	-0.0187	-0.1262	-0.1019
C2 & C4	-0.0119	-0.0022	-0.0031	-0.0430	-0.0331	-0.0492	-0.0349	-0.0344	-0.1210	-0.0334
C2 & C5	-0.0215	-0.0008	0.0000	-0.0036	-0.0029	-0.0527	-0.0319	0.0000	-0.0249	0.0000
C2 & C6	-0.0459	-0.0260	-0.0058	-0.0387	-0.0069	-0.0173	-0.0623	-0.0146	-0.0461	-0.0223
C2 & C7	-0.0017	-0.0015	-0.0044	-0.0054	-0.1127	-0.0132	-0.1623	-0.0140	-0.1425	-0.1313

C2 & C8	0.0000	-0.0012	-0.0045	-0.0773	-0.1200	-0.0121	-0.0115	-0.0644	-0.1530	-0.1169
C2 & C9	-0.0011	-0.0011	-0.0039	-0.0048	-0.0040	-0.0126	-0.1225	-0.0141	-0.1130	-0.0776
C2 & C10	-0.1375	-0.0156	-0.1171	-0.0090	-0.0308	-0.0882	-0.0149	-0.0469	-0.0370	-0.0289
C3 & C4	-0.0128	-0.0043	-0.0085	-0.0538	-0.1112	-0.0598	-0.0365	-0.0541	-0.1127	-0.0644
C3 & C5	-0.0183	-0.0038	0.0000	0.0000	-0.0509	-0.0632	-0.0334	0.0000	-0.0081	0.0000
C3 & C6	-0.0429	-0.0348	-0.0028	-0.0523	-0.0193	-0.0281	-0.0648	-0.0072	-0.0294	-0.0557
C3 & C7	-0.0029	-0.0001	-0.0013	-0.0016	-0.1602	-0.0097	-0.1673	-0.0067	-0.1377	-0.1571
C3 & C8	0.0000	-0.0054	-0.0023	-0.0838	-0.1614	-0.0085	-0.0125	-0.0771	-0.1492	-0.1415
C3 & C9	-0.0027	-0.0071	-0.0009	-0.0013	-0.1114	-0.0094	-0.1289	-0.0078	-0.1014	-0.1192
C3 & C10	-0.1391	-0.0205	-0.1280	-0.0049	-0.0219	-0.0998	-0.0136	-0.0608	-0.0344	-0.0263
C4 & C5	-0.0222	-0.0010	0.0000	-0.0244	-0.0170	-0.1489	-0.0064	0.0000	-0.0040	0.0000
C4 & C6	-0.0136	-0.0272	-0.0015	-0.0916	-0.0019	-0.1374	-0.0099	-0.0665	-0.0250	-0.0035
C4 & C7	-0.0130	-0.0004	0.0000	0.0000	-0.1378	0.0000	-0.1119	-0.0556	-0.1335	-0.1190
C4 & C8	-0.0065	-0.0014	-0.0094	-0.0991	-0.1421	-0.0249	-0.0067	-0.1154	-0.1456	-0.1047
C4 & C9	-0.0144	-0.0013	0.0000	-0.0559	-0.0639	-0.0876	-0.0100	-0.1089	-0.0961	-0.0239
C4 & C10	-0.1149	-0.0156	-0.1325	-0.0248	-0.0197	-0.1636	-0.0234	-0.1069	-0.0298	-0.0278
C5 & C6	-0.0244	-0.0079	-0.0130	-0.0109	-0.0134	-0.0598	-0.0067	-0.0136	-0.0084	-0.0082
C5 & C7	-0.0097	-0.0076	-0.0162	-0.0149	-0.0505	-0.0214	-0.0513	-0.0116	-0.0336	-0.0385
C5 & C8	-0.0211	-0.0005	-0.0044	-0.0408	-0.0592	-0.0188	-0.0098	-0.0035	-0.0494	-0.0365
C5 & C9	-0.0115	-0.0010	-0.0077	-0.0024	-0.0003	-0.0423	-0.0002	-0.0091	-0.0004	-0.0012
C5 & C10	-0.0615	-0.0065	-0.0315	-0.0091	-0.0576	-0.0778	-0.0373	0.0000	-0.1019	-0.0765
C6 & C7	-0.0009	-0.0007	-0.0069	-0.0015	-0.0958	-0.0022	-0.1178	-0.0014	-0.0868	-0.1082
C6 & C8	0.0000	-0.0145	-0.0057	-0.1010	-0.1044	0.0000	-0.0031	-0.0842	-0.1074	-0.0960
C6 & C9	-0.0556	-0.0285	-0.0059	-0.0496	-0.0085	-0.0471	-0.0194	-0.0256	-0.0046	-0.0138
C6 & C10	-0.1525	-0.0317	-0.1107	-0.0181	-0.0395	-0.1412	-0.0225	-0.0686	-0.0510	-0.0390
C7 & C8	-0.0126	-0.0056	-0.0082	-0.0523	-0.1577	-0.0154	-0.0554	-0.0727	-0.1421	-0.1433
C7 & C9	-0.0069	-0.0056	-0.0096	-0.0106	-0.1293	-0.0143	-0.1419	-0.0220	-0.1133	-0.1319
C7 & C10	-0.0969	-0.0043	-0.0815	-0.0179	-0.0404	-0.0600	-0.0466	-0.0581	-0.0612	-0.0481
C8 & C9	-0.0166	-0.0006	-0.0018	-0.0758	-0.1264	-0.0058	-0.0052	-0.0920	-0.1223	-0.1087
C8 & C10	-0.0600	-0.0119	-0.0893	-0.0532	-0.0493	-0.0719	-0.0360	-0.0947	-0.0735	-0.0561
C9 & C10	-0.1244	-0.0145	-0.1049	-0.0065	-0.0375	-0.1008	-0.0244	-0.0776	-0.0601	-0.0458

Table S14: The details on the sensitivity analysis conducted in this study focusing on changes in closeness coefficients in Scenario 2 to a two-at-a-time alteration of criteria weights (by +20%); each raw presents the highest increase of closeness coefficient

	T1	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**	**T9**	**T10**
C1 & C2	0.1559	0.0299	0.2409	0.0816	0.0391	0.0611	0.0171	0.1137	0.0237	0.0025
C1 & C3	0.1659	0.0082	0.2507	0.1283	0.0120	0.1084	0.0238	0.1189	0.0269	0.0130
C1 & C4	0.1898	0.0408	0.2154	0.0858	0.0698	0.0415	0.0113	0.0822	0.0221	0.0075
C1 & C5	0.0792	0.0258	0.0969	0.0701	0.0634	0.0513	0.0147	0.0544	0.0084	0.0196
C1 & C6	0.1987	0.0146	0.2037	0.0412	0.0394	0.0503	0.0128	0.1150	0.0219	0.0086

C1 & C7	0.1695	0.0040	0.2293	0.0647	0.0242	0.0499	0.0124	0.0999	0.0222	0.0042
C1 & C8	0.1995	0.0631	0.2371	0.1001	0.0255	0.0720	0.0137	0.1105	0.0247	0.0106
C1 & C9	0.1731	0.0056	0.2166	0.0473	0.0526	0.0932	0.0126	0.1173	0.0217	0.0071
C1 & C10	0.1189	0.0392	0.1001	0.0502	0.0805	0.0178	0.0132	0.0501	0.0065	0.0212
C2 & C3	0.0185	0.0023	0.2168	0.1314	0.0133	0.1558	0.0136	0.1180	0.0054	0.0102
C2 & C4	0.0244	0.0382	0.1451	0.0113	0.0012	0.0922	0.0045	0.0465	0.0025	0.0086
C2 & C5	0.0423	0.0226	0.0431	0.0188	0.0167	0.0490	0.0392	0.0162	0.0381	0.0187
C2 & C6	0.0833	0.0003	0.1341	0.0010	0.0031	0.0996	0.0057	0.1105	0.0024	0.0045
C2 & C7	0.0021	0.0002	0.1730	0.0001	0.0029	0.1034	0.0055	0.0806	0.0023	0.0024
C2 & C8	0.0728	0.0733	0.1885	0.0574	0.0071	0.1289	0.0065	0.1013	0.0043	0.0105
C2 & C9	0.0057	0.0005	0.1533	0.0007	0.0029	0.1448	0.0056	0.1148	0.0023	0.0026
C2 & C10	0.0190	0.0365	0.0628	0.0381	0.0448	0.0274	0.0380	0.0397	0.0624	0.0208
C3 & C4	0.0516	0.0200	0.1925	0.1610	0.0142	0.1577	0.0111	0.0768	0.0052	0.0063
C3 & C5	0.0380	0.0267	0.0483	0.1129	0.0103	0.0497	0.0249	0.0408	0.0313	0.0382
C3 & C6	0.0967	0.0036	0.1784	0.0837	0.0159	0.1563	0.0121	0.1266	0.0049	0.0329
C3 & C7	0.0251	0.0035	0.2140	0.1234	0.0158	0.1632	0.0121	0.1045	0.0049	0.0307
C3 & C8	0.0880	0.0562	0.2259	0.1783	0.0206	0.1801	0.0131	0.1208	0.0069	0.0069
C3 & C9	0.0377	0.0036	0.1961	0.0936	0.0158	0.1894	0.0120	0.1303	0.0049	0.0321
C3 & C10	0.0175	0.0271	0.0651	0.0566	0.0144	0.0829	0.0237	0.0408	0.0550	0.0400
C4 & C5	0.0186	0.0105	0.0191	0.0255	0.0435	0.0222	0.0841	0.0103	0.0609	0.0249
C4 & C6	0.1634	0.0199	0.0304	0.0000	0.0000	0.0776	0.0000	0.0849	0.0000	0.0076
C4 & C7	0.0532	0.0000	0.1134	0.0000	0.0000	0.0809	0.0028	0.0115	0.0000	0.0075
C4 & C8	0.1620	0.1465	0.1573	0.0942	0.0000	0.1303	0.0000	0.0602	0.0000	0.0038
C4 & C9	0.0757	0.0000	0.0679	0.0000	0.0010	0.1589	0.0000	0.0918	0.0000	0.0075
C4 & C10	0.0091	0.0698	0.0317	0.0221	0.0834	0.0077	0.0837	0.0259	0.0967	0.0279
C5 & C6	0.0520	0.0228	0.0441	0.0000	0.0103	0.0562	0.0614	0.0564	0.0490	0.0467
C5 & C7	0.0452	0.0207	0.0500	0.0045	0.0000	0.0586	0.0773	0.0149	0.0302	0.0455
C5 & C8	0.0368	0.0456	0.0504	0.0734	0.0000	0.0434	0.0692	0.0339	0.0385	0.0000
C5 & C9	0.0455	0.0208	0.0463	0.0000	0.0247	0.0630	0.0698	0.0608	0.0556	0.0463
C5 & C10	0.0498	0.0199	0.0744	0.0212	0.0748	0.0545	0.1077	0.0349	0.0989	0.0513
C6 & C7	0.0856	0.0027	0.0557	0.0053	0.0033	0.0619	0.0012	0.0745	0.0017	0.0206
C6 & C8	0.1307	0.0496	0.0802	0.0217	0.0077	0.0851	0.0024	0.0902	0.0035	0.0106
C6 & C9	0.0940	0.0030	0.0381	0.0066	0.0023	0.1018	0.0014	0.1015	0.0009	0.0223
C6 & C10	0.0437	0.0252	0.0604	0.0496	0.0373	0.0189	0.0427	0.0470	0.0550	0.0311
C7 & C8	0.0596	0.0403	0.1164	0.0324	0.0096	0.0824	0.0017	0.0441	0.0051	0.0114
C7 & C9	0.0010	0.0046	0.0000	0.0042	0.0045	0.0018	0.0008	0.0014	0.0031	0.0000
C7 & C10	0.0192	0.0196	0.0688	0.0464	0.0286	0.0191	0.0430	0.0419	0.0457	0.0268
C8 & C9	0.1087	0.0399	0.1503	0.0039	0.0059	0.1687	0.0013	0.1152	0.0028	0.0108
C8 & C10	0.0362	0.0840	0.0549	0.0377	0.0410	0.0410	0.0586	0.0349	0.0675	0.0055
C9 & C10	0.0194	0.0214	0.0636	0.0484	0.0418	0.0595	0.0442	0.0479	0.0564	0.0299

Table S15: The details on the sensitivity analysis conducted in this study focusing on changes in closeness coefficients in Scenario 2 to a two-at-a-time alteration of criteria weights (by -20%); each raw presents the highest reduction of closeness coefficient

	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
C1 & C2	-0.0203	-0.0033	-0.0313	-0.0092	-0.0093	-0.0067	-0.1266	-0.0136	-0.1515	-0.0262
C1 & C3	-0.0246	-0.0203	-0.0394	-0.0221	-0.0711	-0.0150	-0.1358	-0.0177	-0.1497	-0.0013
C1 & C4	-0.0285	-0.0092	-0.0246	-0.0100	-0.0077	-0.0055	-0.1069	-0.0049	-0.1464	-0.0269
C1 & C5	-0.0325	-0.0414	-0.0325	-0.0189	-0.0152	-0.0869	-0.0521	-0.0030	-0.0916	-0.0088
C1 & C6	-0.0244	-0.0118	-0.0237	-0.0304	-0.0072	-0.0040	-0.1108	-0.0119	-0.1414	-0.0009
C1 & C7	-0.0217	-0.0324	-0.0242	-0.0085	-0.0280	-0.0036	-0.1106	-0.0104	-0.1556	-0.0037
C1 & C8	-0.0295	-0.0090	-0.0324	-0.0132	-0.0264	-0.0098	-0.1139	-0.0138	-0.1532	-0.0612
C1 & C9	-0.0222	-0.0289	-0.0242	-0.0224	-0.0055	-0.0058	-0.1094	-0.0118	-0.1405	-0.0019
C1 & C10	-0.0094	-0.0265	-0.0296	-0.0361	-0.0368	-0.0158	-0.0538	-0.0288	-0.0777	-0.0138
C2 & C3	-0.0094	-0.0358	-0.0204	-0.0105	-0.1201	-0.0138	-0.1269	-0.0097	-0.0741	-0.0163
C2 & C4	-0.0136	-0.0060	-0.0100	-0.0012	-0.0407	-0.0068	-0.0749	-0.0119	-0.0447	-0.0575
C2 & C5	-0.1163	-0.0574	-0.0843	-0.0071	-0.0118	-0.0992	-0.0218	-0.0214	-0.0155	-0.0093
C2 & C6	-0.0010	-0.0268	-0.0092	-0.0763	-0.0682	-0.0050	-0.0843	-0.0049	-0.0484	-0.0230
C2 & C7	-0.0469	-0.0552	-0.0091	-0.0398	-0.0876	-0.0046	-0.0819	-0.0042	-0.0737	-0.0299
C2 & C8	-0.0052	-0.0054	-0.0158	-0.0038	-0.0866	-0.0100	-0.0873	-0.0071	-0.0663	-0.0847
C2 & C9	-0.0247	-0.0500	-0.0094	-0.0679	-0.0552	-0.0056	-0.0812	-0.0048	-0.0438	-0.0253
C2 & C10	-0.0531	-0.0205	-0.0820	-0.0707	-0.0281	-0.0165	-0.0320	-0.0539	-0.0378	-0.0153
C3 & C4	-0.0075	-0.0230	-0.0178	-0.0162	-0.1187	-0.0162	-0.1105	-0.0039	-0.0661	-0.0256
C3 & C5	-0.0967	-0.0714	-0.0666	-0.0253	-0.0771	-0.0753	-0.0420	-0.0131	-0.0156	-0.0098
C3 & C6	-0.0030	-0.0576	-0.0168	-0.0253	-0.1325	-0.0140	-0.1158	-0.0086	-0.0666	-0.0017
C3 & C7	-0.0024	-0.0762	-0.0169	-0.0153	-0.1456	-0.0140	-0.1157	-0.0084	-0.0875	-0.0017
C3 & C8	-0.0074	-0.0041	-0.0232	-0.0185	-0.1453	-0.0192	-0.1203	-0.0111	-0.0820	-0.0663
C3 & C9	-0.0024	-0.0725	-0.0169	-0.0169	-0.1254	-0.0142	-0.1139	-0.0085	-0.0634	-0.0017
C3 & C10	-0.0271	-0.0218	-0.0644	-0.0349	-0.0575	-0.0040	-0.0434	-0.0445	-0.0381	-0.0149
C4 & C5	-0.1295	-0.0672	-0.1610	-0.0041	-0.0053	-0.1503	-0.0105	-0.0646	-0.0072	-0.0062
C4 & C6	0.0000	-0.0289	-0.0001	-0.1145	-0.0493	0.0000	-0.0310	0.0000	-0.0244	-0.0332
C4 & C7	-0.0065	-0.0718	0.0000	-0.0660	-0.1456	0.0000	-0.0118	-0.0377	-0.0757	-0.0453
C4 & C8	-0.0036	-0.0040	0.0000	-0.0001	-0.0862	-0.0008	-0.0281	0.0000	-0.0607	-0.1225
C4 & C9	-0.0048	-0.0634	0.0000	-0.1045	-0.0189	0.0000	-0.0189	0.0000	-0.0129	-0.0372
C4 & C10	-0.0048	-0.0634	0.0000	-0.1044	-0.0188	0.0000	-0.0189	0.0000	-0.0129	-0.0371
C5 & C6	-0.0364	-0.0170	-0.1600	-0.0935	-0.0168	-0.0371	-0.0169	-0.1060	-0.0209	-0.0070
C5 & C7	-0.0666	-0.0851	-0.1475	-0.0750	-0.0289	-0.1174	-0.0229	-0.0039	-0.0170	-0.0078
C5 & C8	-0.1483	-0.1005	-0.1118	-0.0344	-0.0589	-0.1287	-0.0229	-0.0345	-0.0294	-0.0086
C5 & C9	-0.0802	-0.0335	-0.0809	-0.0049	-0.0582	-0.0904	-0.0174	-0.0183	-0.0166	-0.0710
C5 & C10	-0.1219	-0.0302	-0.2158	-0.0720	-0.0233	-0.1343	-0.0366	-0.0839	-0.0373	-0.0162
C6 & C7	-0.0053	-0.0608	-0.0020	-0.0991	-0.0687	-0.0028	-0.0267	-0.0041	-0.0429	-0.0009
C6 & C8	-0.0129	-0.0065	-0.0093	-0.0420	-0.0675	-0.0092	-0.0319	-0.0076	-0.0359	-0.0579
C6 & C9	-0.0059	-0.0575	-0.0017	-0.1113	-0.0419	-0.0059	-0.0285	-0.0061	-0.0186	-0.0011
C6 & C10	-0.0101	-0.0249	-0.0917	-0.1022	-0.0317	-0.0174	-0.0314	-0.0423	-0.0406	-0.0155
C7 & C8	-0.0078	-0.0074	-0.0120	-0.0051	-0.0846	-0.0092	-0.0196	-0.0047	-0.0625	-0.0568

C7 & C9	-0.0003	0.0000	-0.0043	-0.0001	0.0000	-0.0057	0.0000	-0.0031	0.0000	-0.0008
C7 & C10	-0.0296	-0.0297	-0.0764	-0.0771	-0.0366	-0.0174	-0.0311	-0.0503	-0.0463	-0.0154
C8 & C9	-0.0073	-0.0314	-0.0087	-0.0588	-0.0825	-0.0069	-0.0354	-0.0036	-0.0505	-0.0751
C8 & C10	-0.0186	-0.0271	-0.0960	-0.0659	-0.0269	-0.0140	-0.0253	-0.0617	-0.0345	-0.0427
C9 & C10	-0.0252	-0.0281	-0.0862	-0.0965	-0.0294	-0.0022	-0.0307	-0.0415	-0.0405	-0.0154

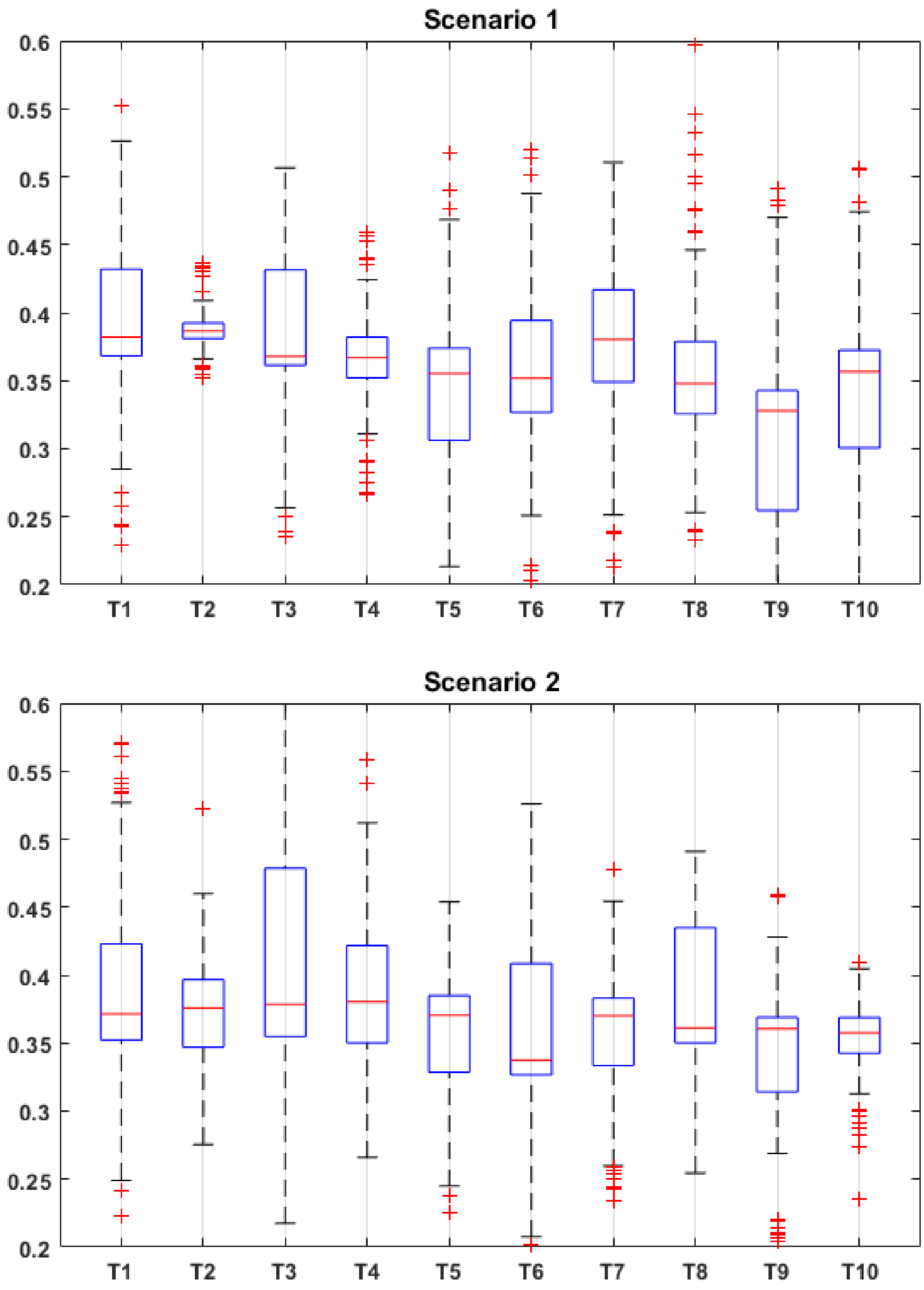

Figure S4: Sensitivity of closeness coefficients in each scenario to a two-at-a-time alteration of criteria weights (by ±20%) for the wastewater treatment trains evaluated in this study

S8. The user-interface of the IMCMEDM tool

The user-interface of the IMCMEDM tool is as illustrated in the following figures. By default, the tool is launched with four options (**Figure S5**):

1. Data entering: where the data is can be input and surveys can be undertaken.
2. Run: which is employed after 'Data entering' to run the model in each scenario, and illustrates different tables and graphs of each simulation.
3. Display', which includes the schematic representation of each water reuse technologies.
4. Instruction: which guides the user through the process of undertaking a survey and includes some information about technologies, criteria, and the model.

By selecting the option 'data entering', the next step is to select a scenario to which the data are referred (**Figure S6**). After selecting a scenario, there are consecutive 11 tables which should be filled in. the first of these 11 is the pair-wise comparison between criteria (**Figure S7**) by which weight of each criterion can be can calculated. The next ten tables represent rating the technologies with respect to each criterion (C1 to C10) (**Figure S8**). After completing the data entering stage, the model can be run for each scenario and various figures and tables show the results of each scenario (**Figure S9**).

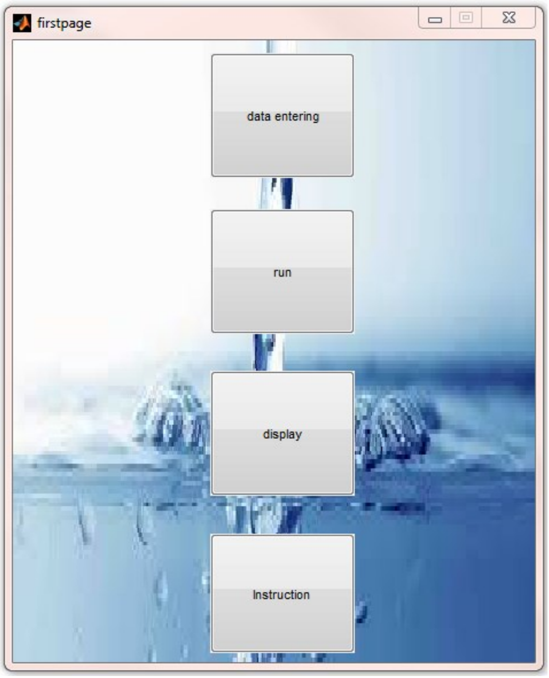

Figure S5: The IMCMEDM tool user interface; first page

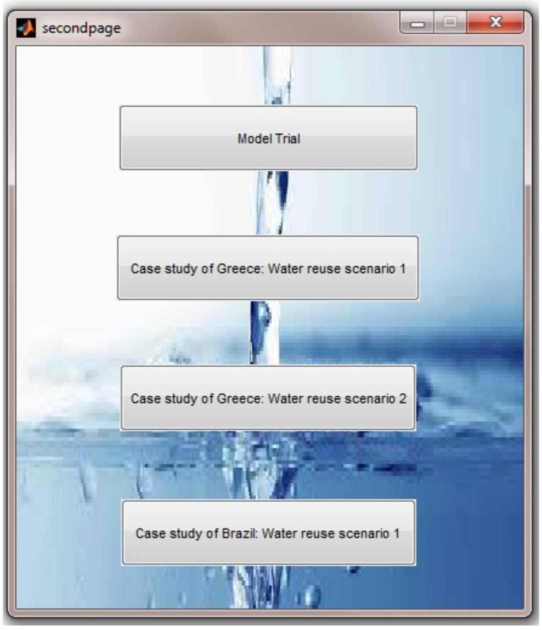

Figure S6: The IMCMEDM tool user interface; second page

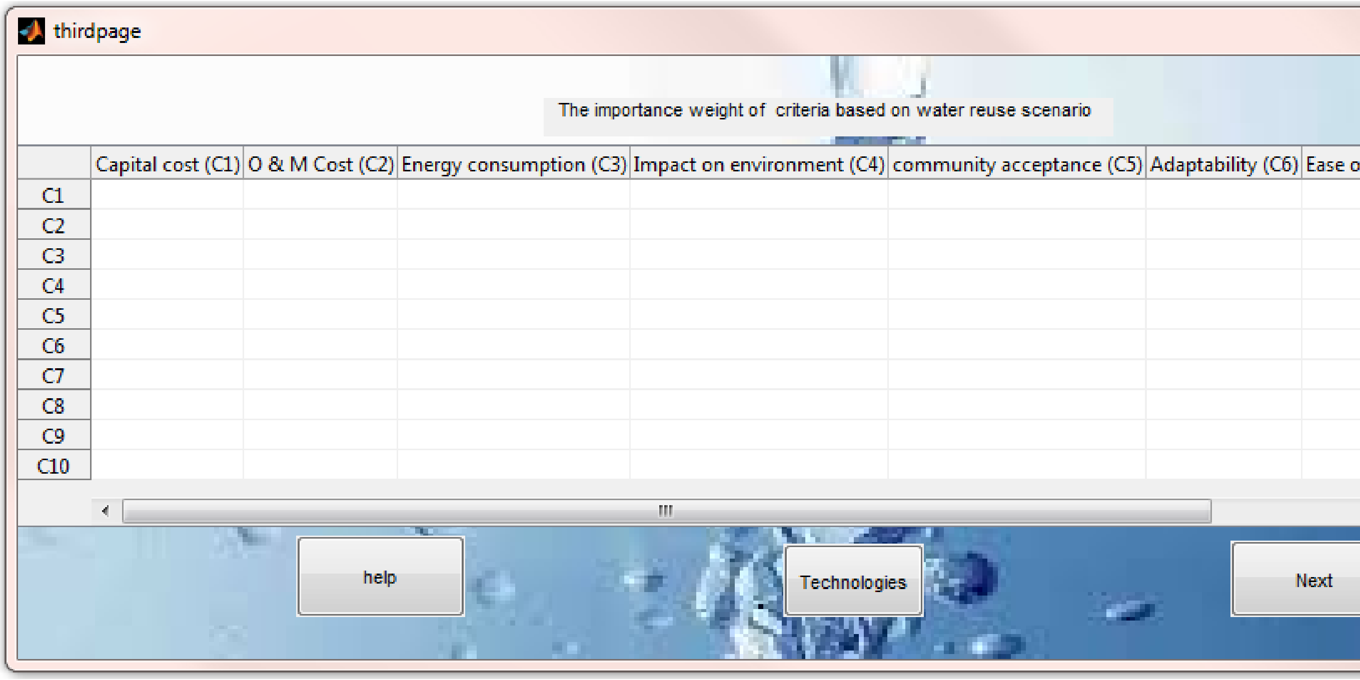

Figure S7: The IMCMEDM tool user interface; pair-wise comparison of the criteria

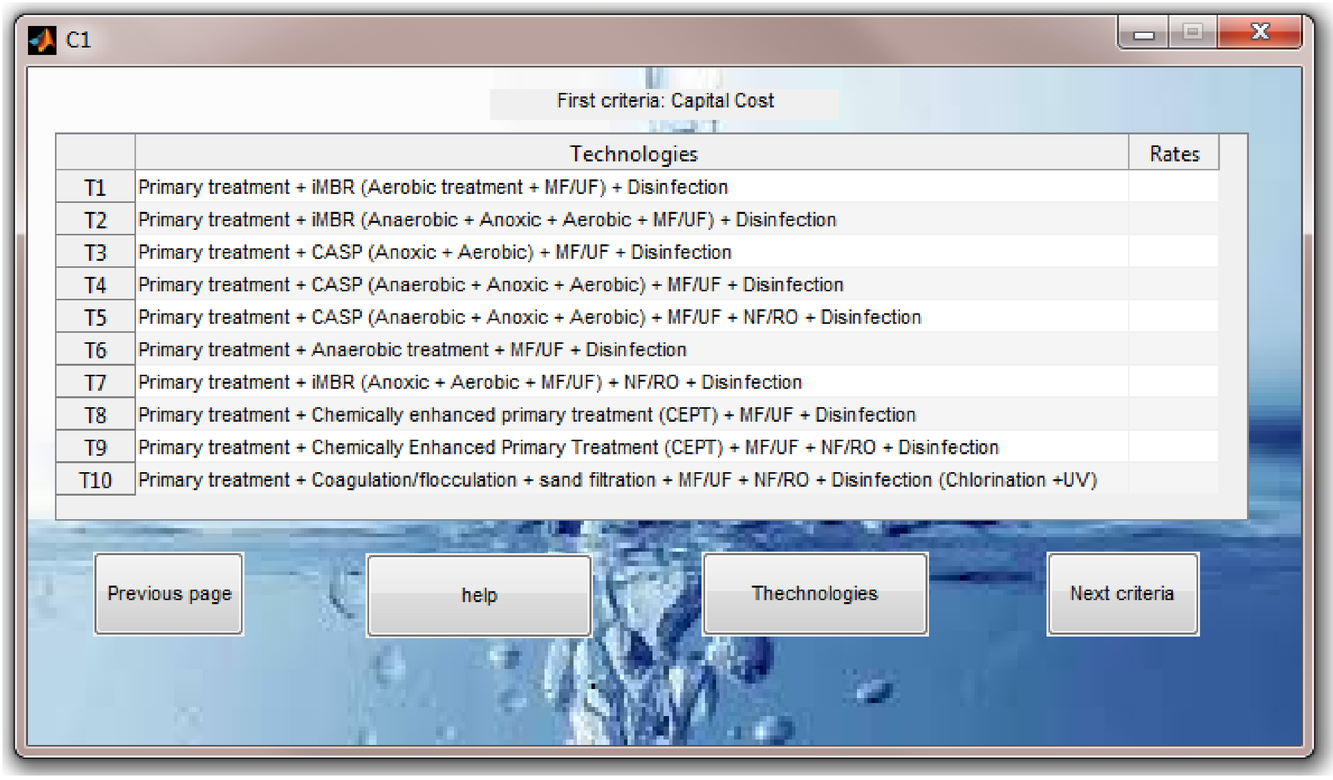

Figure S8: The IMCMEDM tool user interface; the page of rating the technologies with respect to a criterion

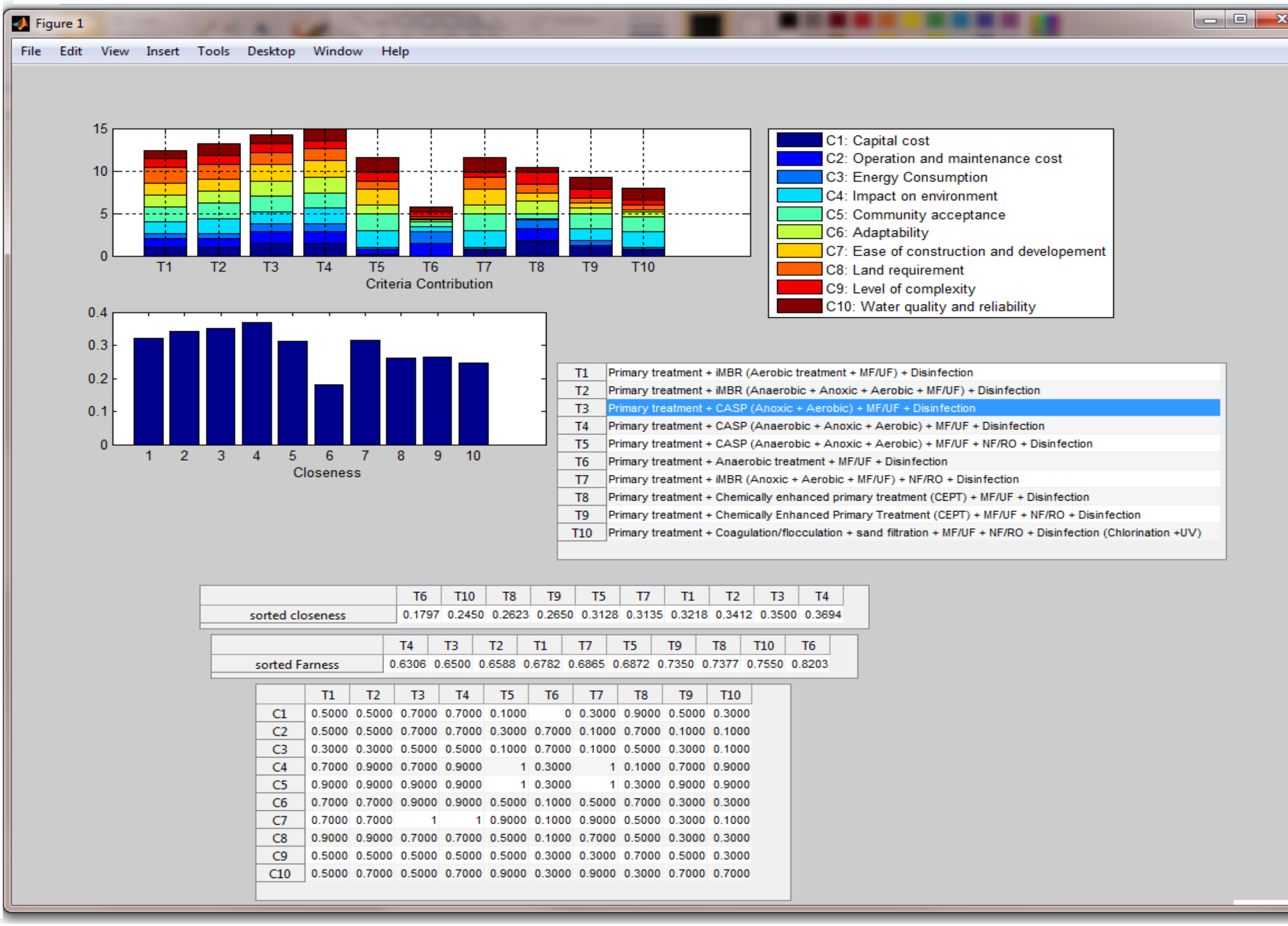

Figure S9: The IMCMEDM tool user interface; result page